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1.—THE PRE-CAMBRIAN GEOLOGY OF PART OF THE SOUTH COAST OF WESTERN AUSTRALIA.

By

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ABSTRACT.

A geological reconnaissance of part of the South Coast of Western Australia is outlined. The major tructures in the Archaean rocks strike in an E.N.E. direction in marked contrast to the N.W. trend in the emainder of the Western Australian shield. The Archaean rocks include para-schists and gneisses and ssociated meta-basic igneous rocks, all of which have been extensively granitized and migmatized yielding suite of granitic and charnockitic gneisses which have in places been mobilized to yield intrusive granites. roterozoic rocks are represented by low-to medium-grade metasediments with associated concordant basic neous intrusives and their deposition has been followed by intense overthrusting from the S.S.W. The ast phase in the Pre-Cambrian record of the South Coast was the intrusion of basic dykes which are condered to be co-magmatic with the quartz dolerite suite of the remainder of the Western Australian shield.

CONTENTS.

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I. INTRODUCTION.

This paper is an attempt to summarize present information about the "old rocks" in a strip of country about 600 miles long, which borders on the south coast of Western Australia between E. longitudes 116° 30′ and 124°.* We also give a tentative interpretation of the broad structure of the Strip, in the hope that others may be moved to examine the country further and so confirm or modify our suggestions.

Many observers have reported on small parts of the Strip, but the only systematic mapping of any but small patches was that done early in this century by Woodward and Talbot in the Ravensthorpe District (Woodward, 1909). Reports on smaller areas by Blatchford, Ellis, Jutson and Simpson, Maitland, Maclaren, Wilson, Woolnough, and others, are mentioned later.

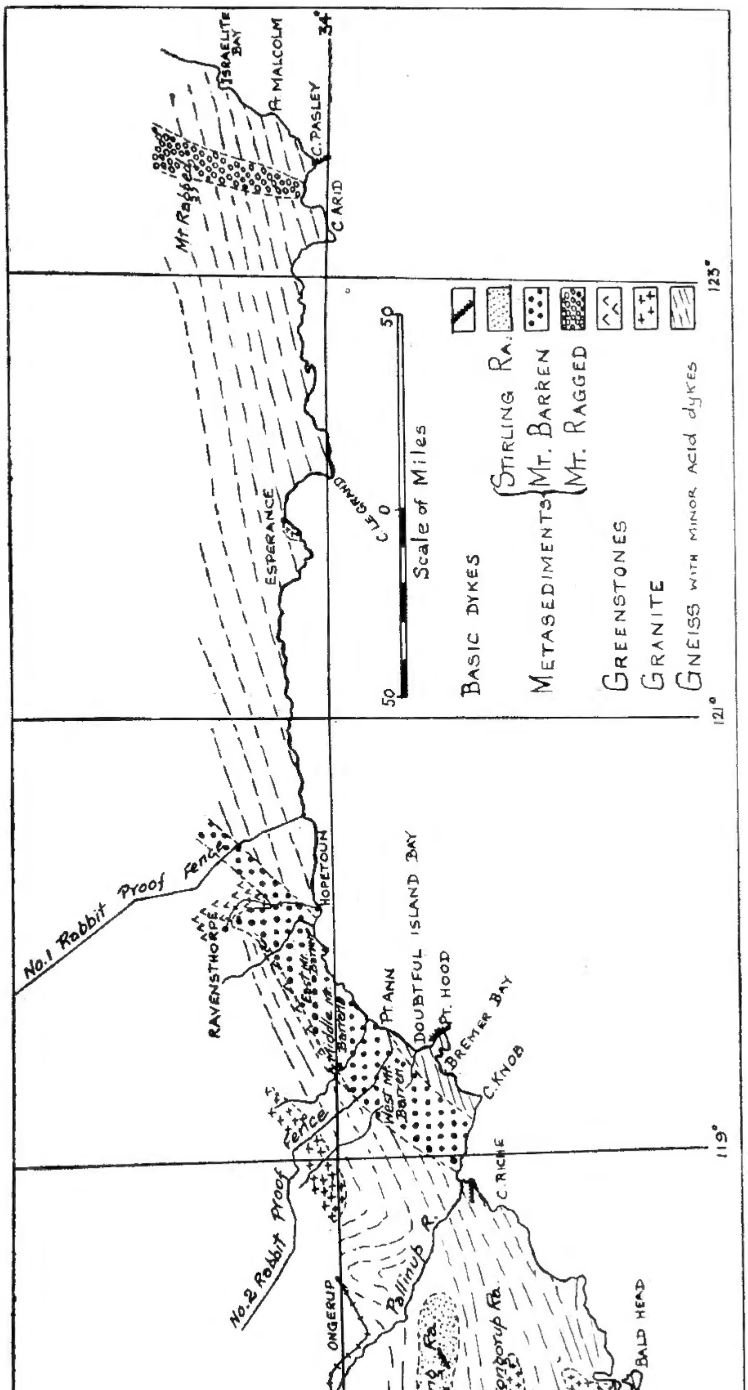
The first and most extensive exploration, made by the first Surveyor General, J. S. Roe, in 1848–9, crossed the eastern three-quarters of the Strip and went far beyond it to the Bremer Range, 100 miles to the north. Roe's journey was a remarkable achievement. His party, consisting of six men and eleven horses, travelled generally north-east from Cape Riche, discovering and naming the Bremer Range and other features. Roe then travelled south-east to Mt. Ragged, seen and named by Eyre in 1841, but not previously visited. Roe named Peak Charles and other hills en route. Thence he went westwards, approaching the coast near Esperance Bay. After that he generally kept near the sea, but made many detours to circumvent inlets and examine the country. He arrived at Cape Riche in January, 1849, with his party intact, having covered 1,000 miles in hitherto unknown and very inhospitable country.

Between 1928 and 1949 Phillipps and Clarke made ten short excursions from Perth to parts of the Strip. The total time spent in geological work there was about 120 days. Prider, except for a visit to the Stirling Range with Phillipps in January, 1949, and to Albany in January, 1951, has not seen the rocks in the field, but has studied nearly all the specimens collected and is responsible for the petrographic part (Section V) of this paper.

Detailed field-records would only be wearisome and of very little use to readers of this paper, so, in Section IV (in which the petrography of Section V is given full weight) we have summarized our conclusions as to the Pre-Cambrian geology of different parts of the Strip—each part being somewhat distinct geologically from its neighbours. We have quoted the conclusions of previous observers in much more detail than our own, hoping thus to avoid mis-representation of their opinions. The rock-specimens (occasionally referred to thus "(13309)" in the text) and detailed accounts of our field-work are kept in the Dept. of Geology, University of W.A. where other geologists may consult them.

Plate I shows the extent of country and our conception of the broad geology of the areas on which we did any work, or regarding which information has been obtained from the writings of others. This map makes clear, without further elaboration, that our field-work was very "scrappy." Further, since our investigations have been spread over twenty years, our interpretation and appreciation of observations have changed, so that another visit to places like Doubtful Island Bay and Point Ann, which we visited in the early thirties, might very much alter our views. Text Figure 1, a "picture" of our present ideas about the arrangement of the "old rocks," is based on insufficient data, and later work will no doubt change it considerably.

* The reasons for calling this tract "The Strip" in preference to terms such as "Province," "Region," etc., are given by Clarke and Phillipps (1952) which might be read in conjunction with this paper.



Text fig. 1.

The South Coast Strip: Generalised geological sketch map. The hachure lines for the gneisses are parallel to the foliation.

We are greatly indebted to Mr. W. J. Kirkby, Acting Chief Draftsman of the Lands and Surveys Department, for the preparation of Plate I from our maps. The major part of the travelling and other expenses (including cost of rock analyses) has been met by Commonwealth Research Grants, and this assistance is gratefully acknowledged. Acknowledgments of other help, given by many in the State, are made in the body of the paper.

II. OUTLINE OF PRE-CAMBRIAN GEOLOGY.

The bed-rocks were, in Pre-Miocene times, eroded to an irregular surface, the lower parts of which have been covered with sediments of Miocene and later ages, to a depth, in places, of 200 feet and more. There is no direct proof of the age of the bed-rocks, but, from their close resemblance to Pre-Cambrian rocks in other parts of Western and South Australia, they are thought to be Pre-Cambrian. They vary from gneisses and coarse granulites, through high-grade schists and quartzites, to low-grade phyllites, slates, and even to unmetamorphosed sandstones. In most places the bed-rocks have been intensely folded, the major axes of folding trending E.N.E., but there are indications that, immediately north of the coastal strip discussed here, there is a pronounced change in general trend to north, or even north-west. Igneous rocks of various kinds, but chiefly acidic, invade all the assumedly Pre-Cambrian rocks mentioned above, except the unmetamorphosed sandstones; like similar rocks elsewhere in the Western Australian Shield these intrusions are also regarded as Pre-Cambrian.

III. STRUCTURE.

Hills (1946, pp. 69-70), relying, we believe, mainly on notes which we had supplied after our first visits to the Strip, suggested that the regional strike is easterly to north-easterly. Our later observations confirm Hill's generalization, except that perhaps the angular discrepancies that we think occur at Kundip between the trend of the Barrens rocks and that of the Ravensthorpe greenstones (*see* IV D below), and, again, between the Mount Ragged metasediments and the Ongerup-Israelite Bay gneisses (*see* IV F), are difficult to fit into the continuously curving structure shown by Hills (1946, fig. 1).

The easterly trend has been observed only as far from the coast as 50 miles at the most. We do not know of any geological reports on the country between latitudes 33° 30′ S. and 32° 30′ S., but, somewhere in that area, the trend must change to the general N.W. strike of the "greenstone" belts in the Central Goldfields.

Along the Israelite Bay-Norseman track, the only part, except near Albany, where we made any geological notes far from the coast, the prevailing strike is apparently N.N.E. Also we are indebted to Mr. R. Hare for the information, obtained when he was a member of the Soils Division of C.S.I.R.O., that, near Draper Hill, about 10 miles S.S.W. of Ongerup, the strike of the gneiss for 4 or 5 miles is consistently N.N.E., the dip E., and that, from a study of air photos, it is likely that these outcrops are on the west limb of a south-pitching syncline. At Ravensthorpe (Woodward, 1909, pp. 10, 12, 14) the general strike is N.W. These three groups of observations, though widely separated, suggest that a pronounced structural change occurs in about lat. 33° 30′. S.

IV. GENERAL GEOLOGY.

A. Long Point—Torbay Head.

These notes include the Rocky Gully Area* on the Frankland River, 40 miles north of the coast, but otherwise are confined to the coastline.

The predominant rocks are various gneisses. The following are the most frequent types :—even-grained granitic gneiss (IA3)†, granitic gneiss with basic bands (IIID), garnetiferous gneiss (IF3) and hypersthene-bearing gneiss (ID3).

The regional strike of the gneisses is between east and N.N.E. They are not generally very much contorted, but at Point Irwin and Point Hillier they have been much crumpled and fractured with the formation of fault breccia.

Along the east side of West Cape Howe Promontory, north of Torbay Head, gneissic rocks, which in their variety are more akin to the gneisses of the Albany-Point Hood division than to those farther west, are exposed.

A type of rock, not discovered elsewhere in this part, occurs in the Rocky Gully area, near the east bank of the Frankland River, about 1¾ miles below the crossing of the Mt. Barker/Manjimup road, where a graphite vein was prospected in about the year 1921. The small workings have collapsed but Blatchford (1922 a, p.48) describes them as being on a 3 in. to 6 in. seam of graphite striking east and dipping north at 75° to 85°. He states that the vein contains " too much iron and mica to be of any commercial value " and that it occurs in a " dense clay," which, judging from our specimens, (23305,–6) collected from the old dumps, is a highly weathered band of graphite schist running parallel to the general trend of the gneiss.

Coarse granite (IVA1) invades the gneisses in various places, including Rocky Gully, and is in turn cut by narrow bands of fine, even-grained granite (IVB).

Pegmatite dykes cut across all the preceding rocks. Basic dykes occur at various localities such as Long Point (V B 1, three feet wide, striking 345° and dipping 80° west), Point Hillier (V A 2 six feet and 15 feet wide striking 280°, and V C 1 and V C 2 more than 2 chains wide striking 300°) and Knapp Head (V C 2 in three dykes up to four feet wide striking S.E. and dipping 80° or more to the S.W.). Basic dykes were also noted in the Rocky Gully area.

A rather unusual dyke rock (23259), a porphyritic micro-granite (IV C), occurs at Point Hillier. This dyke is approximately 15 feet wide and strikes north-west compared with the more E.-W. strike of the dolerites.

Quartz dolerite (V A 1) makes up nearly all the west side of West Cape Howe Promontory (Prider, 1948, p.68). Near the base of the promontory, on the west side, this basic rock can be seen to invade very coarse granitic gneiss, of which it contains a xenolith, and on Buttress Point, about half a mile east of the tip of West Cape Howe, there is a steep intrusive contact with the gneiss in one place, while, farther south, the basic rock is, to all appearances, overlain by gneiss. At the tip of West Cape Howe there is a very conspicuous patch of white rock. This patch, which is surrounded by dolerite,

* Where Clarke spent some days as guest of the soil-survey party led by Mr. Robert Smith, Regional Officer, C.S.I.R.O. Division of Soils.

† These symbols are explained in Section V.

is visible from Knapp Head, 7 miles away. Whitish, apparently banded rock also outcrops amongst the breakers at the foot of the cliff. These exposures were inaccessible to us, but might well be either gneiss or granite. We suggest that the bulk of West Cape Howe is composed of a large flat-dipping dyke.

Just north of the township of Denmark is an area of which Hosking and Burvill (1938) made a soil survey, and in which Carroll states (1945, p.414) that the following succession occurs :—

(a) Gneisses.
(b) Sillimanite schist, quartzite. } interbedded.
(c) Dolerite, possibly a sill cutting (a).

She considers the dolerite to be an intrusion about 300 ft. thick, dipping N.E. fairly steeply ; it is unmetamorphosed and cuts the metamorphic rocks, the chief of which is garnetiferous quartz-felspar-biotite gneiss ; a basic gneiss or schist and sillimanite schist and quartzite interbedded with the gneisses also occur. Dr. Carroll has kindly allowed us to see her field-notes, from which it appears that the prevailing strike is E.N.E.

B. Albany—Point Hood.

Our field-work in this part was mainly along the coastline, but we made some notes on the Porongorup Range, 20 miles north of Albany, and on the country north of Cape Riche, as far as Ongerup.

The Pre-Cambrian rocks are similar to those of the Long Point-Torbay Head division, but it is convenient to separate the two, because, in the Albany-Point Hood part, the gneisses are more varied, the intrusive granites bulk more largely, and the later basic intrusives are less prominent.

The commonest type of gneiss is the biotite-bearing granitic gneiss (I A 3) but many other interesting varieties have been found, particularly along the south side of Cheyne Bay (just north of Cape Riche) and in the mile of rocky coastline which separates the entrance of Princess Royal (Albany) Harbour from Middleton Beach, both of which areas are characterised by the presence of charnockitic gneisses.

Maitland (1924, p. 6) states that the gneissic rocks on Location 486 on the Pallinup River about 8 miles from its mouth trend east and west, and enclose an almost vertical graphite vein 2 to 3 feet wide ; also that they " contain some dark black bands of hornblende gneiss (1/3665)." The graphite vein proved to contain 30% of ash and to be useless for anything except perhaps stove-polish. This occurrence recalls that on the Frankland River mentioned above. A chemical analysis of the hornblende gneiss specimen mentioned by Maitland was published in the Annual Report for 1925 of the Government Chemist of W.A. (p. 9) under the name of " gneissic quartz epidiorite." Prider has re-examined this specimen and finds it to be a quartz-plagioclase-hornblende gneiss (III A 2) (see Section V of this paper).

The dominant strike of the gneisses between Albany and Point Hood varies from E.N.E. to east, but, as would be expected in closely folded rocks, there are local changes to any point of the compass, thus (information from Mr. R. Hare and Dr. Dorothy Carroll) the prevalent strike on the coastline north of Breaksea Island, and on Mount Manypeak is northerly. Near Graves Hill and Chillilup on the Pallinup River, where it is likely that we are in the north-south structure (Section III) noted by Mr. Hare farther north, the strike is N.N.W.

Besides being intensely folded nearly everywhere, the gneisses are faulted and brecciated in many places. We noticed this particularly at Cape Riche, near the mouth of Willyun Creek, about 7 miles south-west of Cape Riche and both east and west of Cape Knob. In the much faulted gneiss on the west side of Dillon Bay (which is immediately east of Cape Knob) there is not only much faulting but also a " sandstone dyke " (24119) 15 feet wide. Near the mouth of Willyun Creek the gneisses are faulted and there is a 4 ft. band of fault breccia netted with pseudotachylyte (24128).

Granite, intrusive into the gneiss, is the next most abundant rock in this part. It is well exposed at Cave Point and elsewhere on the promontory that ends in Bald Head, on the coast between Albany and Middleton Beach, on Mts. Melville and Clarence at Albany, and on the coast east of Warriup Hill.*

In these and other localities, inland and on the coast, two distinct types of granite, an older, porphyritic, and a younger, fine- and even-grained, occur. The fine-grained granites occur generally as flat-dipping dykes in the gneisses and porphyritic granites.

Pegmatite dykes and quartz veins, penetrating both gneisses and granites are found in almost every exposure and are particularly well developed at Point Irby. Near Point Hood a pegmatite contains large euhedral crystals of microcline (16572) to 8 inches long showing the development of 001, 110, 130, 010, $\bar{1}01$, $\bar{1}\bar{1}1$.

Basic dykes, invading all the above-mentioned rocks, occur at various places between Albany and Point Hood. Charles Darwin in Chapter VII of his " Geological Observations on Volcanic Islands " wrote that at Albany the granitic rocks " are in many places intersected by trappean dikes ; in one place I found ten parallel dikes ranging in an east and west line ; and not far off another set of eight dikes, composed of a different variety of trap, ranging at right angles to the former ones." Also Maitland (1907, p. 31) speaks of " numerous dykes of greenstone " which traverse the " granite of the promontory separating Princess Royal Harbour from King George Sound." Again, Jutson and Simpson (1917, p. 48) write :—" Intrusive into the granite are numerous basic dykes (dolerite and basalt) which range in width from an inch to many yards . . . . At the brick pit about three miles to the north-west of Albany, a decomposed basic dyke cuts through not only the granite, but also the over-lying marine sediments. This evidently belongs to a later series of basic dykes than any of those intrusive into the granite . . . . " We have not seen the dykes mentioned by Darwin, Maitland, and Jutson and Simpson. The only basic dykes noted at Albany were :—(1) a serpentinous dyke (7833) on the coast just north of King Point lighthouse and (2) a dolerite dyke (32188) 2 chains wide striking 150° and intrusive into the porphyritic granite at 5 chains S.W. from Hartman's Granite Quarry at the end of Grey Street on the southern slope of Mt. Melville which was found by Prider in 1951. It is evident that the numerous " trappean " dykes mentioned by Darwin and Maitland are really the basic bands and lenses which occur in the gneisses and not the younger dolerite intrusions. Moreover there is, as noted by Prider (1948, p. 79), very considerable doubt about the " decomposed basic dyke " recorded by Jutson and Simpson as intrusive " through not only the granite but also the overlying marine sediments " (= the Plantagenet beds of Miocene age).

* About 40 miles N.E. of Albany. There is another Warriup Hill about 8½ miles west of Cranbrook

Specimens of basic dyke rocks were collected at several places both inland (*e.g.*, uralitised dolerite (20,004) at Chillilup on the Pallinup River and Needleup between Ongerup and Jarramongup) and along the coast, where basic dykes were noted at Ledge Point (24831), Point Irby (20018) and at Point Hood (16571). Two parallel dolerite dykes, one twenty feet and the other ten feet wide occur approximately 1 mile north of Point Irby. These dykes, which strike E/W and dip 75° to the south, are of basaltic olivine dolerite (VD 2) in the chilled margins and quartz dolerite (VA 1) in the medium-grained central parts, and descriptions of them are given in the petrography section of this paper. On the south coast of the Point Hood promontory about 2 miles west of the actual Point is a dolerite dyke the chilled margin of which is a basaltic olivine dolerite (VD 2) similar to that at Point Irby. This dyke which strikes 150° has been described by Clarke & Phillipps (1952).

C. Stirling Range.

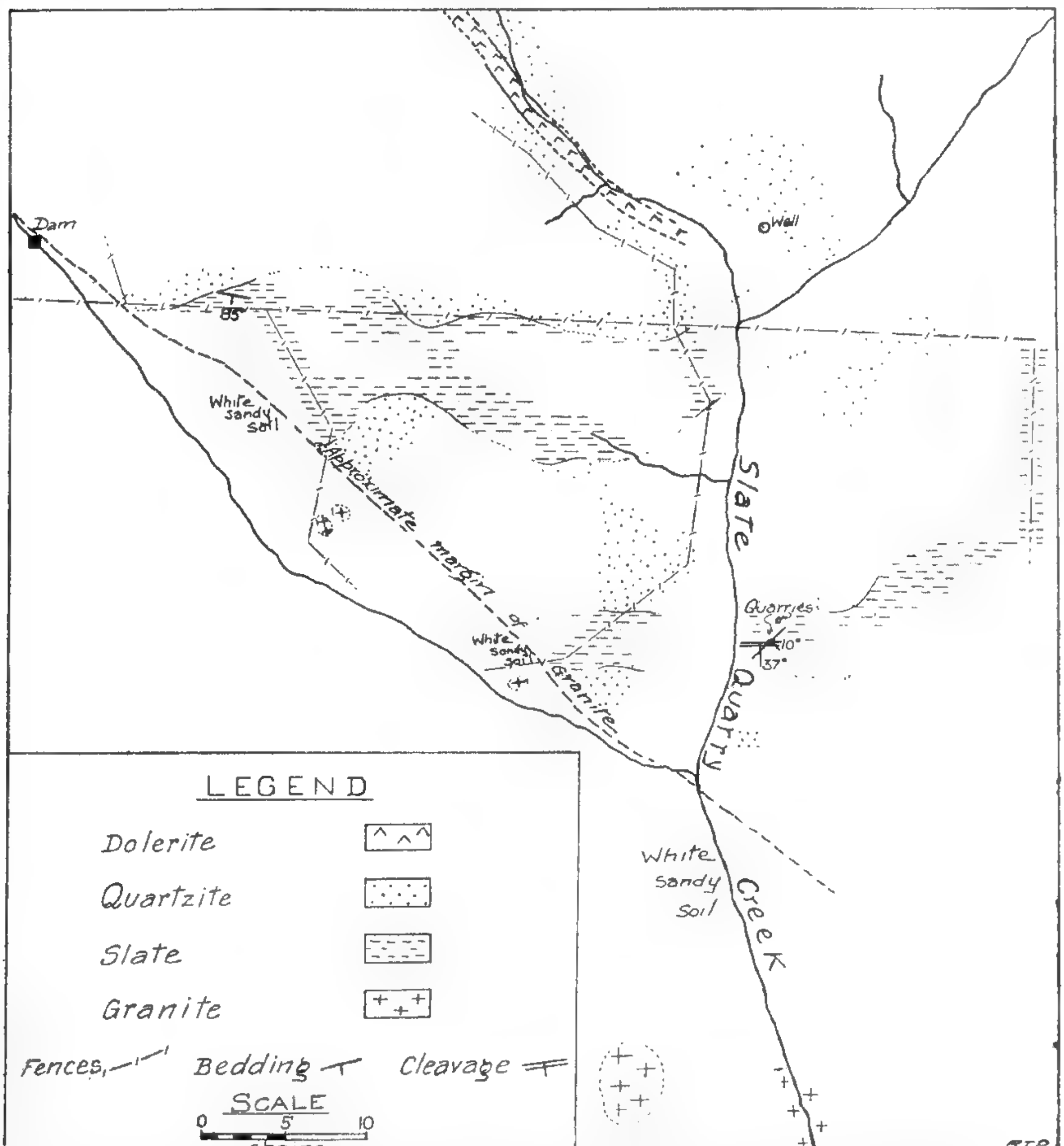
The Stirling Range is a remarkable belt of hills rising abruptly 2000 or even 2500 ft. above the tableland, which is 800 or 900 ft. above the sea. The range runs east and west for nearly 50 miles and is nowhere more than 10 miles wide. In November, 1835, it was named by J. S. Roe when, in making a journey from "Swan River overland to King George's Sound, in company with the Governor, Sir James Stirling," he had his "first glimpse of an elevated picturesque range lying about 40 miles north from Albany."

The results of a geological reconnaissance of the Stirling Range have been described by Woolnough (1920). Woolnough's paper is notable because it records work done single-handed in an area which is mostly, as he says, covered with "extraordinarily dense prickly scrub" and "angular rubble," varied by "great precipitous faces." Woolnough concludes that the range consists of a mass of ripple-marked and current-bedded quartzites, alternating with slates, which in places have been metamorphosed to phyllites. The mass he considers to be at least 3,000 ft. thick, and he states that the rocks, although generally almost horizontal, are locally very considerably crumpled, and, in places, overthrust. In one place he found a dyke of "ophitic quartz dolerite." He suggests that, on the north, south, and east the rocks are heavily faulted and come in contact with older gneisses and greenstones, whereas on the west, they are invaded by Pre-Cambrian granite.

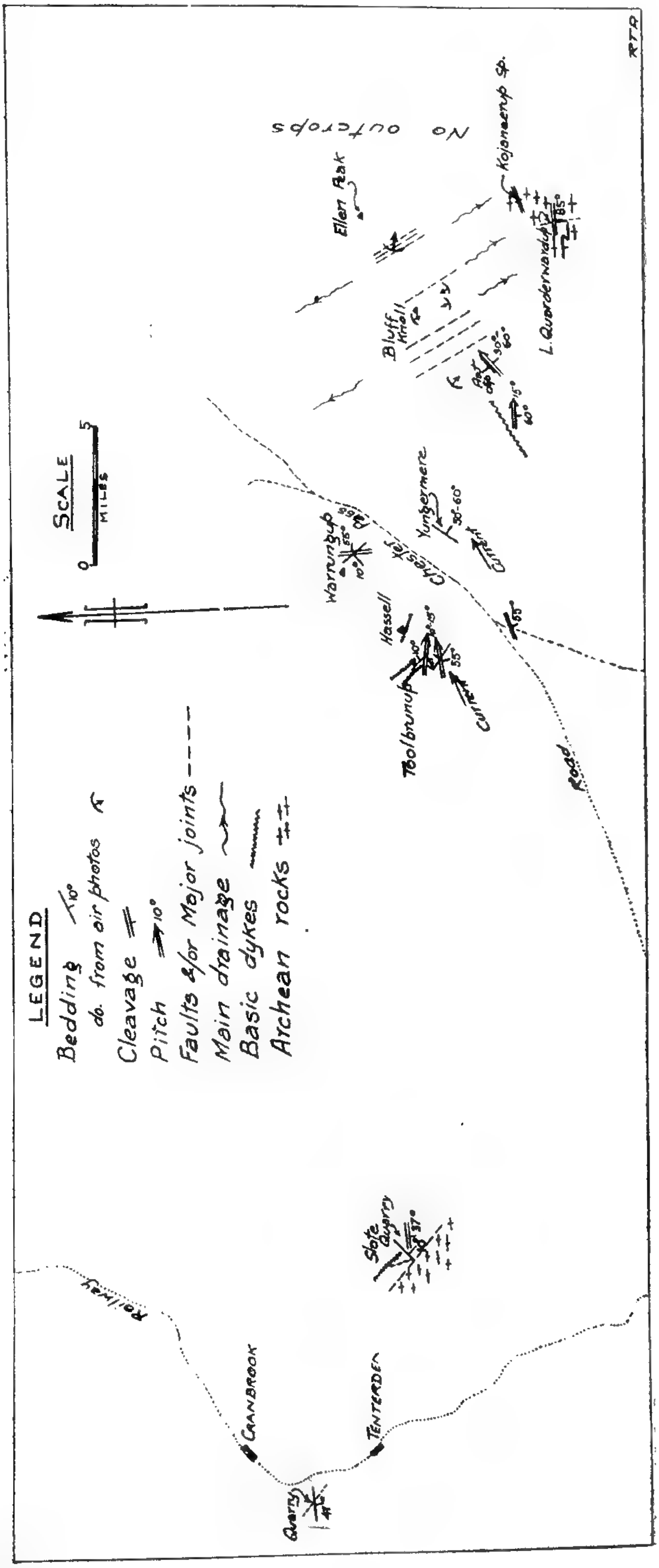
Warriup Hill, 8½ miles west of Cranbrook, is composed of cross-bedded sandstones striking N.W. and dipping N.E. at 15°, and Woolnough (1920, p. 80) says that it is "an outlier of the peculiar formation which builds up the main range." This suggestion is supported by the occurrence of dense, very fine grained purplish quartzite of the Stirling Range beds in a quarry on the west side of the Perth-Albany road at ½-mile south of the 201-mile peg. Prider examined this quarry in January, 1949, and noted that the rocks exposed are ripple-marked purplish quartzites which strike 85° and dip 47° to the south and which are traversed by close-spaced vertical joints striking 310°. Graded bedding, seen in thin sections of this rock, indicates that the sequence at this spot is normal.

Feldtmann (1921) states that, about 1½ miles E.N.E. of Sukey Hill and nearly 4 miles east of Cranbrook railway station, three barite veins occur in "quartzite." The veins strike nearly east and are almost vertical. Feldtmann observed only one doubtful strike of the quartzites, which was N.N.W. He found, other than quartzite outcrops, only a small outcrop of epidiorite and "what are either two aplite dykes, or aplitic marginal portions of a granite mass, about 30 chains W.N.W. and 50 chains N.N.W. respectively, of Sukey Hill." He considers that "it seems reasonable to regard the barite

as derived from a deep-seated magma." It is interesting to note in connection with the occurrence of the barite veins in the Stirling Range beds at Cranbrook that barite veins also occur in the slates and quartzites of the Cardup Series in the Darling Scarp where they are considered (Prider, 1943, p. 51) to be genetically related to the intrusive quartz dolerites. Both in the Stirling Range and the Darling Scarp areas we find therefore a sequence of low-grade meta-sediments intruded by quartz dolerite dykes and containing barite veins. It has been suggested (Prider, 1943, p. 52) that the Stirling Range beds belong to the Nullagine System (of Proterozoic age) as do the Cardup Series, *i.e.*, they are younger than the granites. Woolnough however considers that the Stirling Range sediments are intruded by granite and describes (1920, p. 91) the intrusive relations of the granite to the sediments at a point an eighth of a mile west of the slate quarry on Loc. 2772. In view of the significance, so far as the age of the Stirling Range beds is concerned, of this contact we re-examined the vicinity of the slate quarry but at the point indicated by Woolnough as the contact we could find only slates with interbedded bands of quartzite. Prider in 1949 also examined this area and located granite, a medium even-grained variety, at 15 chains W.S.W. from the southern slate quarry (see text figure 2). In Slate Quarry



Text fig. 2.
Geological sketch map of vicinity of Tenterden Slate Quarry.



Text fig. 3.

The Stirling Range: Sketch map showing structures observed by R. T. Prider.

Creek the closest granite outcrops to the slate quarry are at 27 chains downstream where coarse porphyritic granite outcrops. Nowhere was the actual contact between the granitic rocks and the Stirling Range beds exposed but from the mapping based on the nature of the soil the contact appears to trend 310° which is oblique to the strike of the beds (48°) and to the cleavage developed in them (85°). This contact appears to be a fault rather than an igneous contact as described by Woolnough. Moreover Woolnough (1920, p. 91) says in connection with this contact that " At the immediate point of contact the granite is intensely acid, and passes into the slates in the form of vein quartz loaded with partially to almost completely digested and assimilated fragments of jasper "—Prider when examining this area found the white quartz rock at 10 chains W.S.W. from the slate quarry, a rock which at first sight appears to be white vein quartz but which on closer examination is seen to be a tightly cemented fine conglomeratic quartzite with well-rounded water-worn quartz granules to 3 mm. diameter (25324). The same type of material is interbedded with the slates and quartzites at 10 chains S.W. of the quarry where Woolnough (1920, p. 92) says " a tongue of quartz porphyry intrudes the quartzite." Specimens of quartzite collected by Prider in this particular spot could easily be mistaken for quartz porphyry except for the rounded nature of the quartz " phenocrysts." The conclusion that we have reached from these observations is that the contact here between the granite and the Stirling Range beds is, most probably, a faulted rather than an igneous one.

Prider in January, 1949, made some observations at various places in the range and these are set down in text fig. 3 together with some structural data obtained from a study of air photos of the area. Insufficient field work has been carried out to determine the structure of the range but Prider's work indicates that :—

(i) The Stirling Range beds are post-granite and pre-dolerite and therefore most probably are of Nullagine (Proterozoic) age.

(ii) The basic dykes in this area are more abundant than at first supposed. Woolnough (1920, p. 92) says " throughout the length and breadth of the range only one basic dyke was definitely located . . . . one . . . . which crosses the ridge of Toolbrunup immediately to the west of the highest summit." We found a dolerite dyke on the east face of Mt. Hassell and Prider has found two east-west striking dolerite dykes on Phillipps' Spur to the south of Toolbrunup, another striking E.N.E. near the southern face of the range at 4¼ miles south-east of the highest point of Yungermere and a fourth dyke (of quartz diorite) striking N.W. at 35 chains N.N.W. from the Tenterden Slate Quarry on Location 2772.

(iii) There are zones of intense disturbance at various places such as Phillipps' Spur south of Toolbrunup, half-way up the west face of Yungermere, and at 4¼ miles S.E. of the crest of Yungermere, where there has been much overfolding from the south. Within these zones the quartzites and phyllites are intensely contorted and the drag folds pitch 10° to 15° in the direction 110° magnetic. In all the disturbed zones seen in the field the pitch was always flat in the direction of 100° to 120° magnetic. Moreover the cleavage also strikes in this direction and dips from 30° to 60° to the south and the drag structures read south block up. The same structures were noted in the less disturbed beds in the Tenterden Slate Quarry.

(iv) In the flat-bedded sections of the Range away from the intensely disturbed zones mentioned in (iii) the sequence, as judged from graded bedding (seen in thin sections from oriented specimens) and current bedding, is normal. This is the case at the quarry on the west side of the Perth-Albany highway at ½-mile south of the 201-mile peg, at Toolbrunup, Mt. Hassell, Warrungup, and Yungermere.

(v) Current-bedding observations on Phillipps Spur (Toolbrunup) and Yungermere indicate that the source of the sediments was from the W.S.W.

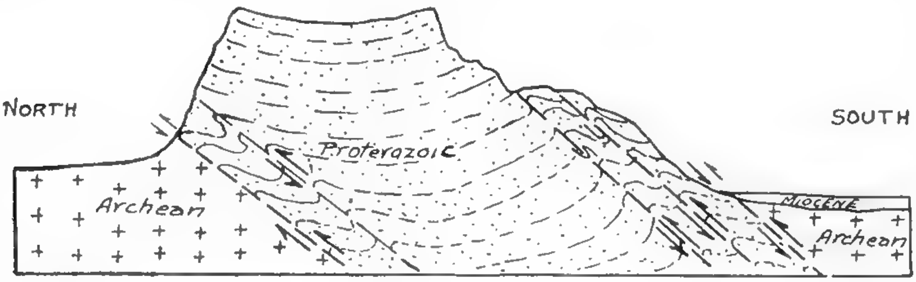
(vi) The structure of the Bluff Knoll mass is a broad gentle syncline with an E–W axis as has been noted by Woolnough (1920, p. 103).

(vii) The Bluff Knoll-Isongerup section of the Range is traversed by many nearly vertical fractures striking approximately 320° magnetic. These straight fractures are very prominent on the aerial photographs and can be traced out in the foothills both to north and south in the stream pattern. The air photos of the S.W. trending dolerite dyke (visited in the field) at 4¼ miles south-east of Yungermere show that this set of vertical fractures is of a post-dyke age as they produce an offsetting of the vertical dyke where they traverse it. It is interesting to note that this set of fractures nearly parallels the mapped contact between the granite and Stirling Range sediments at the Tenterden Slate Quarry, which, as has been indicated above, is most probably a faulted contact, and is, moreover, parallel to the well developed vertical joints in the quartzites near the Perth-Albany highway at 201½ miles from Perth.

Tentative conclusions regarding the development of the Range which may be drawn from these observations are :—

(a) The Stirling Range sediments were a shallow water facies (*see* petrographic notes in Section V.E. below) derived from higher country to the S.W.

(b) The deposition of the sediments was followed by overthrusting from the direction approximately 200° along parallel thrusts dipping about 45°S. (text fig. 4). There was a considerable strike-slip component in this overthrusting with the south (hanging-wall) block moving to the east causing the general easterly pitch of the drags associated with the overthrusting. This is deduced from structures seen on the southern face of the range. Woolnough (1920, p. 103) records " overthrust faulting from south to north, with formation of crush conglomerate, on Warrungup " which supports this hypothesis. We have made no observations along the northern face of the Range but feel that observations to the north of Bluff Knoll and Isongerup would throw much light on the structural history of the Range. The low-grade metamorphism of the Stirling Range beds was effected during the period of overthrusting.



Text. fig. 4.
Diagrammatic cross section to illustrate suggested structure of Stirling Range.

(c) The next event was the intrusion of quartz dolerite dykes—petrographic examination (*see* Section V.F. below) indicates that these basic intrusions have not been subjected to the overthrusting movements.

(d) Then followed a further period of earth-movement which was responsible for the development of the vertical fractures striking approximately 310°. Judged from the distribution of granite and Stirling Range sediments at the western end of the range the movement on these fractures was mainly strike-slip with the N.E. block moving S.E.

The sequence of events outlined above differs considerably from the conclusions reached by Woolnough (1920, p. 112) that " the sediments must have been preserved from denudation in a senkungsfeld [and] it is probable that the latest differential movement has resulted in the uplift of the sediments." Much more field work is required however before any definite conclusions can be reached regarding the structure of this area.

D. The Barrens.

This division is a strip, 20 or 30 miles wide, which extends N.E. for about 80 miles from the lower part of the Gairdner River. It includes the conspicuous West, Middle, and East Mount Barrens, Mount Bland, and the Whoogarup and Eyre Ranges. The 10 miles of rugged country comprising Middle Mount Barren and the Whoogarup Range should be interesting geologically, but we were able to see only something of its southern edge along the coast for 4 miles S.W. of Hamersley Inlet and for 1½ miles N.E. of Dempster Inlet.

The Barrens division seems to be made up entirely of metasediments interspersed with sills or dykes of basic rock. The regional strike is N.E. but the rocks are generally closely folded and the strike varies greatly.

One's first impression is that quartzites are the most abundant rocks, but this may well be a mistake, for their strong resistance to erosion and weathering leaves them standing above big expanses of obscured ground, which is probably underlain by more easily disintegrated schists. In any case the quartzites and other metasediments vary rapidly along the strike ; thus we find quartzites grading into muscovite quartzite and thence into quartz-albite-muscovite-biotite schist ; again, quartzose phyllite may pass into mica schist or into coarse quartz-muscovite-chlorite schist, or again in a few places into kyanite schist. The more pelitic rocks are generally light grey in colour but in places they are much darker and contain a good deal of fine granular, ilmenite. In a few places we found narrow bands of metaconglomerate interbedded with ilmenite-bearing quartz-chlorite-muscovite schist (metagreywacke). This conglomerate is intra-formational, for its dragged-out pebbles are fragments of the interbedded schist. There are relics of cross-bedding in some of the coarser-grained rocks. Although calcareous rocks are rare, a band of red marble-breccia outcrops among quartzites and schists on the coast about 1 mile west of Hamersley Inlet and, in the Phillips River about 10½ miles below the crossing of the road to Ravensthorpe is a bed of limestone which is probably the continuation of the " grey marble " mentioned by Simpson (1948, p. 326).

It seems then that the principal rock-assemblage in the Barrens division was once a series of shallow water sediments.

Although the rocks vary greatly along the strike, there is a larger development of the finer-grained, more pelitic type with minor intercalations of quartzite, between Point Ann (at the end of No. 2 Rabbit-Proof Fence) and Point Charles (at the mouth of the Fitzgerald River), in the Gairdner River (from 5 to 35 miles above its mouth), in the Fitzgerald River (from 14 to 23 miles below the crossing of the Ravensthorpe Road) and in the Phillips River (from 8 to 14 miles below the same crossing).

The Phillips River section is particularly interesting, and should repay much more thorough investigation than ours, for not only does it show the occurrence of limestone already mentioned, but also an exposure of granite among the metasediments. Further work may show the character of the contact which we could not find. Incidentally, we did not succeed in finding anywhere a contact between the gneisses of the other divisions and the metasediments. A. C. Gregory (1849) found that on the north side of East Mt. Barren the rocks are "stratified and softer, in some places quite black, the colour being caused by the great quantity of carbonaceous matter." It is likely then that in this part, which we have not seen, there are graphite schists.

We have not examined the Fitzgerald River except near the crossing of the old track about 5 miles above the mouth of the inlet, and near the crossing of the Ongerup-Ravensthorpe road. Coal has been reported from the Fitzgerald and the main object of J. S. Roe's exploration in the latter part of 1848 was to examine this coal deposit. The coal is probably of Tertiary age and the only interest it has here is the incentive it provided for the examination of the basement rocks in this area. Thus Nicolay (1876) visited this occurrence and his map indicates that the schists hereabouts strike N.E. Blatchford (1922 b, p. 17) records that the rocks underlying the coal "have a general east and west strike, with a prevailing southerly dip."

If we are right in supposing that the Barrens rocks continue north-eastwards across the Phillips River, then there must be a marked decrease in the quantity of quartzite relative to schists. This change is reflected in the topography for, in contrast with the rugged Whoogarups, Eyre Range, etc., the relief is mild and there are no rough quartzite hills, although fairly conspicuous outcrops of quartzite do occur.

The dominant rock in this part is a sericitic phyllite, which is bleached almost white by weathering and contains many thin quartzose layers which, when the phyllite weathers, break into small discs and cover the ground, as for example at the deserted Kundip townsite. We did not examine the coast east of Hopetoun, having been informed that it is sandy for a long distance, and so have not seen any unweathered exposures of the phyllites.

On the Ravensthorpe-Esperance Road, about 16½ miles from Ravensthorpe, at the crossing of Bandalup Creek, quartz-felspar-muscovite schist, originally a fine-grained arkosic sandstone, is interbedded with a hornblende schist (schistose quartz-plagioclase amphibolite) and extends for at least a mile east of Bandalup Creek.

We do not know of any account of the geology of the country immediately north and north-east of Bandalup Creek, except a note by Ellis (1941) that "the weathering of basic dykes, intrusive into quartzites and mica schists, has produced magnesite." Therefore we have not shown the Barrens rock-association as extending farther east than Bandalup Creek.

Kundip, an almost defunct mining centre less than a mile north of Kundip townsite where the phyllitic series striking N.E. occurs, stands on low ridges at the southern end of a N.W.-trending belt which includes Ravensthorpe (Woodward, 1901 b).

It should be noted that nearly 40 years ago Montgomery (Montgomery & MacLaren, 1914, pp. 17–23) pointed out that at "McCulloch's," an old copper prospect 5 miles north of the mouth of Hamersley Inlet and in a schist phase of the Barrens rock-group, the regional strike is very different from that near Ravensthorpe. In topography and geology the Ravensthorpe belt, which we have not studied, is similar to the greenstone belts of the Goldfields. Kundip may therefore some day give some information about the relationship of the north-easterly striking metasediments of the Mt. Barren belt and the north-westerly striking metamorphic rocks of the Eastern Goldfields.

We found very few intrusions into the metasediments of the Barrens division. A possible granite intrusion in the Phillips River has been mentioned and basic dykes or sills intrusive into the schists and quartzites were noted in the Eyre Range and in the Phillips River. However, many years ago Blatchford (1918, p. 12) stated, regarding the Barren Ranges generally: "At the surface one finds a repetition of quartzites and quartz dolerites standing at a high angle . . . and striking approximately east and west. The prevailing dip is to the south." Petrological examination of the basic igneous rocks from the Barrens rock-group reveals that for the most part they are sheared and completely uralitised quartz dolerites and gabbros, which, because they have been involved in the folding movements which have affected the metasediments, differ from the younger unaltered quartz dolerite dykes (*see* below in Section V.B. of this paper).

E. Ongerup-Israelite Bay.

The inland part of the Strip from near the east end of the Stirling Range to Ravensthorpe, Esperance and Israelite Bay, is a plain, much of which is covered by the Miocene Plantagenet Beds. Pre-Cambrian gneisses and granites with occasional basic dykes are exposed here and there in the broad, shallow valleys and as hills, generally low, which project above the plain. We examined most of the outcrops along the Ongerup-Israelite Bay road, but had not the time to follow up and down the valleys that crossed it, and in which there are likely to be many exposures of the bed-rock. As these valleys cross the regional strike they are likely to yield more information than the much more spectacular coastline which tends to run with the strike. Our inland travels have therefore done little to check the conclusions to which the coastal geology led us. So far as we can learn the Pre-Cambrian rocks along the Ongerup-Esperance road are the same gneisses and granites, with occasional basic dykes, as those which form the coast from Long Point to Point Hood.

The neighbourhood of the graphite and vermiculite occurrences on the Munglinup and Young Rivers, 5 and 15 miles respectively north of the Ravensthorpe-Esperance road, is the only part of the Strip between Ravensthorpe and Esperance which has been geologically examined. Blatchford (1917 and 1919) wrote in 1917 that "more or less basic rocks have intruded the granite. These intrusions vary from narrow dykes . . . . to masses of rock several hundred feet wide." The graphite deposits are "in a small belt of very weathered rock . . . which is entirely encased in a belt of quartz diorite" which strikes in a general N.E. direction and is surrounded by

"granite." He notes that near the surface magnesite and opal have been deposited. Farquharson (Blatchford, 1917, p. 18) made a petrological examination of Blatchford's specimens and concluded that probably "the lode material is in part the alteration product of a granitic pegmatite, in part an extremely weathered and probably sheared basic rock of serpentine or gabbroid affinities which the pegmatite dykes have intruded."

Ellis (1941 and 1944) writes that the graphite and vermiculite deposits are in rocks that are "markedly gneissic with biotite, hornblende, and occasionally garnet the predominant minerals after quartz and felspar," and states that the gneisses contain one or more bands of graphite schist. Near the Young River less than a mile north of the graphite prospect, is a "complex of basic rocks comprising mainly massive hornblendites . . . . . intrusive into interbedded hornblende granulite and biotite gneiss, striking approximately N. and S. and dipping at from 30° to 55° to the east. The basic intrusive rocks, frequently massive and coarse-grained, and the gneissic series, have been invaded by granite and pegmatite."

The distance from the Munglinup River through Esperance to Israelite Bay is about 200 miles by the road and tracks which we took, and all that we know of the geology of this part of the Strip came from two journeys—one by Phillipps and Clarke which took about ten days, and one of about 14 days by Phillipps, accompanied by Mr. A. E. Paton. Phillipps and Clarke on their trip spent two days at Cape Le Grand, one day at Duke of Orleans Bay, one day at the mouth of the Thomas River, and one day at Point Malcolm; they then travelled north to the Eyre Highway, stopping one day at Mount Ragged. Phillipps, on his later journey, spent 7 days at Mount Ragged and 2 at Mount Russell. The balance of the time on both trips was taken up by travelling, with short stops to examine exposures near the route.

With such meagre acquaintance with the rocks in this part of the Strip we can only say that they seem to be the same gneiss-granite complex as that between Long Point and Point Hood, and that their prevailing strike is N.E. to E.N.E. Dolerite dykes are less abundant but pegmatites are more plentiful than in the western part of the Strip.

Maitland (1925, p. 5) states that the main formation in the vicinity of Cape Pasley is "highly micaceous gneissic granite" which "has a general north-east and south-west strike" with "vertical foliation planes." He found at Cape Pasely "a very coarse grained pegmatite dyke, measuring 15 feet in width and having a very considerable horizontal extent" along "the vertical foliation planes" of the gneissic granite. "The pegmatite . . . contains potash mica in . . . small books . . . in addition . . . the dyke contains some large fragments of . . . microcline." He also states that mica occurs "about three miles north of Bellinger Sand Patch in pegmatite dykes as books, from some of which sheets three by four inches could be cut."

Bands of strongly schistose rocks have been already noted much farther west, at Munglinup and the Young River. There is another occurrence of schistose rocks on the floor of a small lake (almost dry in January, 1948) which is half a mile south of the Old Telegraph Line and about six miles south-west of Point Malcolm. A band of hornblende schist, one chain wide, is exposed in a claypan about 4 miles to the E.N.E. of this spot. It is crossed by a graphic pegmatite (24492) and lies parallel to a bed of very coarse quartzite, but gneiss seems to be the prevailing rock.

As stated in another paper (Clarke & Phillipps, 1952) little is known about the geology of the Recherche Archipelago. Woodward (1909, p. 17) wrote that the " granite " which is the bed-rock of Christmas Island (20 miles S.E. of Israelite Bay) is evidently much folded gneiss invaded by porphyritic granite which is pale flesh-coloured, with scattered crystals of orthoclase up to 1 inch in length. This granite gives out dyke-like extensions in which " the rock changes rapidly into pegmatite . . . . Whilst further still from the primary magma these pass almost imperceptibly into quartz veins which occasionally contain a little felspar or mica in the form of large crystals, the latter being mostly biotite. Intersecting the entire series are numerous narrow veins of highly basic fine-grained greenstones containing much magnetite.

Mr. F. G. Forman visited some of the islands of the Recherche in 1942 and has kindly allowed us to use his notes and to examine the specimens he collected. The specimens from Pasley, Middle, Goose, and Christmas Islands indicate that the basement rocks are similar to those of the mainland. They are gneisses with basic bands intruded by fine even-grained granites and by still younger dolerites, the specimen of dolerite from Pasley Island being a fine-grained olivine dolerite (V.D.1). Calc-silicate rocks occur associated with the more granitic gneisses and a rather interesting specimen of grossularite-epidote-diopside granulite somes from Middle Island. The " porphyritic granite . . . . . with scattered crystals of orthoclase up to 1 inch in length " of Christmas Island mentioned by Woodward (1909, p. 17) is undoubtedly similar to the Esperance granite but is not represented in the collection made by Mr. Forman. On Pasley Island the foliation of the gneisses strikes 70° and dips steeply to the south-east and the olivine dolerite dyke 15 ft. wide intrusive into these rocks strikes 330° and is vertical. On Goose Island the strike of the gneisses and associated ilmenitic quartzites is 65° and they dip 30° to 45° S.E. In Goose Island Bay on Middle Island the average strike of the gneisses is N.E. and the dip is 30° to 45° S.E.—the fold axes here are overturned to the N.W. and the drag fold structures pitch from 10° to 20° S.W. From these data it is evident that the general N.E.-S.W. trend of the older Pre-Cambrian rocks of the South Coast strip is maintained in the Recherche Archipelago.

F. Mount Ragged Belt.

Maitland (1925, p. 5) describes Mount Ragged as made up of " granitic gneisses and allied schistose rocks . . . The schists seem to be genetically related to plutonic igneous rocks and probably owe their origin to the transmutation of a granite as a result of the stresses to which it has been subjected since consolidation." Larcombe, in the same report, describes the microscopic features of two of the rocks, and considers both to be " quartzitic " and of sedimentary origin. Prider (section V.A of this paper) also considers these rocks to be high grade meta-sediments.

Mount Ragged and the Russell Range are, like the Barrens, composed of siliceous metasediments and are rugged and precipitous, but their metasediments are more highly metamorphosed.

Mount Ragged is an isolated ridge trending slightly east of north. It is about 3½ miles long, half-a-mile wide at the south and two miles wide at the north end. It consists of steeply dipping muscovite quartzites interbedded with quartz-muscovite schists. Near the south-west end some of the quartz-muscovite schists carry porphyroblastic andalusite (24517-8). Dragfold

A. The metasediments.

As has been shown in the earlier section of this paper dealing with the field occurrence of the rocks there are three distinct areas occupied by rocks of metasedimentary origin. There is firstly the Gairdner River-Phillips River (Barrens) belt in which the metasediments have been intruded by basic igneous rocks (*see* B. below). There is the Mt. Ragged belt approximately 200 miles to the east in which the metasedimentary quartzites are of much higher grade metamorphism and are intruded by pegmatites and because of this are considered to be Archaean. Finally there is the Stirling Range area where the metasediments are of very low grade (chlorite zone) metamorphism and although intruded by dolerite dykes they appear to be younger than the granitic rocks and are therefore post Archaean in age.

In this discussion of the petrography of the rocks of the Strip the metasediments of these three distinct areas will be considered separately—those which may be the equivalent of the Whitestones of the Goldfields areas are dealt with here and the rocks of the post-granite Stirling Range beds are described below under E.

1. *The metasediments of the Gairdner River-Phillips River (Barrens) belt.*

The rocks from this belt consist of various quartz-muscovite-chlorite schists with interbedded quartzites and meta-conglomerates. The grade of metamorphism is low except in the vicinity of West Mt. Barren and East Mt. Barren where we find the sporadic development of kyanite in the schists. A characteristic feature of the rocks examined from this belt was the presence of greenish tourmaline which occurs in small amount in both the quartzites and schists and also the presence of a pale green mica. Biotite is of rare occurrence.

For the purpose of these petrographical notes the available specimens from this belt are subdivided into :—

(a) Quartzites ; (b) schists ; (c) limestones.

(a) *The quartzites.*

Very few quartzites in the collection are free from muscovite and chlorite. Specimen 17489 from 2 miles east of Pabelup Swamp is representative of this mica-free group. It consists entirely of a granoblastic aggregate of quartz in which the average grain-size is 0·3 mm. diameter. The quartz grains have interlocking crenulate boundaries and are generally somewhat elongated (index of elongation = 2). All signs of original clastic structure have been obscured by the complete recrystallisation.

Some of the quartzites of Pt. Ann (*e.g.*, 13316) which are interbedded with the contorted muscovite schists are also comparatively free from mica or chlorite but show the effects of extreme deformation, the quartz grains being lenticular with an average index of elongation, of 8 to 10 (plate II, fig. 1) and showing in addition, very strong undulatory extinction.

The muscovite quartzites form a group intermediate in character between the quartzites and quartz-muscovite schists. Specimen 17480 from the coast 3 miles S.W. of East Mt. Barren is typical. It is fine-grained platy quartzite which tends to split into sheets of the order of ¼inch thick due to

structures indicate that the structure of the south end of Mt. Ragged is an anticline overturned to the east and plunging south at about 12° and at the north end is a syncline plunging north at about 6°, these folds being separated by an anticlinal cross-fold about 2 miles north of the south end of the mountain. The various beds, of which the mountain is composed, outcrop a few feet above the plain at the north end, where they may be readily studied. They strike about 20° east of north in the direction of the Russell Range and the more distant range, which includes Mt. Dean and Mt. Esmond.

The Russell Range strongly resembles Mt. Ragged and lies about 4 miles to the north-east. The south end is composed almost entirely of highly garnetiferous quartz-mica schist containing some large quartz reefs. This is overlain by micaceous schist and micaceous quartzite which appears to make up the bulk of the range. The serrated tops of both Russell Range and Mt. Ragged are composed of a very hard grey quartzite.

It was not possible to visit the Mt. Dean and Mt. Esmond Range, but it appears that it and Wolgrah Hill represent part of the same belt of metasediments. The Pup and Cora Hill, about 15 miles south of Mt. Ragged are undoubtedly similar. Mica Hill, which is reported (but only by hearsay) to show considerable quantities of sillimanite, and which also contains pegmatite dykes carrying books of muscovite, is probably on the western margin of the belt. Again, on the old telegraph line, 30 miles south-south-west of Mt. Ragged, is a belt of coarse quartz rock (24483), perhaps three or four miles wide and striking north-east. On either side of it is gneiss. Some of this belt is reef quartz, but the more flaggy rocks are quartzites.

A muscovite quartzite (24513), which outcrops near the track to Norseman, 8 miles west of Pt. Dempster, is probably near the eastern edge of this belt of metasediments, which would, in that case, be more than 15 miles wide. In view of the high degree of metamorphism of these metasediments and the general trend of the belt, they are most probably contemporaneous with the adjoining gneiss.

V. PETROGRAPHY.

The collection of specimens made by E. de C. Clarke and H. T. Phillipps in the course of their field reconnaissance of the south coast of Western Australia may, for petrographic purposes, be subdivided as follows :—

A. The metasediments of :
   1. The Gairdner R.-Phillips R. (Barrens) belt.
   2. The Mt. Ragged belt.

B. The greenstones associated with the Gairdner R.-Phillips R. metasediments.

C. The gneisses.

D. The intrusive granites.

E. The Stirling Range metasediments.

F. The basic dykes.

(b) *The Schists.*

The schists of the Gairdner River-Phillips River belt include meta-pelites, meta-arenites, and meta-conglomerates. They are of variable mineral composition and grade of metamorphism, varying from sericite phyllites through quartz-chlorite-muscovite schists to quartz-muscovite-biotite schists and kyanite-bearing schists. As with the quartzites of this metasedimentary belt, they are all characterised by the presence of greenish tourmaline and rounded purple zircons as heavy mineral accessories. Typical representatives of the schists are :—

(i) *Quartz-muscovite schist.*

All the schists of this group are fine-grained and phyllitic in character. Specimen 13332 from the coast approximately $\frac{1}{4}$-mile S.W. from Point Charles is typical. It is a fine-grained, pale greenish, silky-lustred, schistose rock which under the microscope consists of elongated plates of pale green non-pleochroic, highly birefringent mica (elongation index averaging 9 in flakes up to 0·15 mm. long), elongate lenticular grains of quartz (elongation index 4) and abundant prisms of opaque, slightly magnetic, ?ilmenite. All these minerals are elongated parallel to the schistosity. The pale green mica has β = 1·61 and (–)2V = 31° and is therefore a muscovite. The accessory constituents are apatite in stout prisms, extremely small zircons, and rare small pale greenish tourmaline prisms. In a similar rock (13312) from Point Ann there is an abundance of greenish brown tourmaline similar to that of the quartzites described above.

Another specimen of this group which is of interest is 17476 from the mouth of a creek approximately three and one-third miles west of the mouth of the Hamersley River. This rock is slightly coarser textured and the original clastic structures are preserved. There is a well-defined current-bedded structure which is emphasized by the presence of heavy mineral bands. The main constituents are quartz (average grain size 0·08 mm. diameter) and green muscovite in the light-coloured bands and green muscovite, black opaque ilmenite, pinkish rounded zircons, granular yellow anatase and a minor amount of quartz in the heavy mineral bands. A heavy mineral separation in bromoform indicates that the heavy fraction constitutes nearly half the mass of the specimen and that it is made up of approximately 60% ilmenite, 20% of zircon and 20% of a yellow, non-pleochroic, highly birefringent mineral with refractive indices much higher than 2·06. This mineral yields positive tests for titanium and is, most probably, anatase. No tourmaline was noted in the heavy fractions.

(ii) *Quartz-chlorite-muscovite schist.*

The rocks of this group are interbedded with and similar in all respects to the quartz-muscovite schists described under (i) above except that they carry in addition a considerable amount of chlorite. The presence of this chlorite-muscovite association is clear evidence of the low grade of metamorphism to which these rocks have been subjected. The type specimen of this group is 13331 from $\frac{1}{2}$-mile south-west of Point Charles—it is a thin-bedded greenish schistose rock in which the flow cleavage is approximately at right angles to the bedding indicating that the specimen is from the axial region of a fold. The lighter-coloured bands contain a higher proportion

the presence of extremely thin muscovite-rich layers. Under the microscope the wide more quartzose bands consist of an equigranular granoblastic aggregate of unstrained quartz grains which average 0·15 mm. diameter. There is a tendency for the quartz grains to be slightly elongated. This elongation is parallel to the schistosity produced by the parallel orientation of small muscovite flakes which are present to the extent of approximately 5%. The muscovite flakes average 0·05 mm. long and generally occur between the quartz grains but some are enclosed within the quartz. Peppered uniformly throughout are small granules of black opaque iron ore and occasional grains of tourmaline. In the very thin muscovite-rich layers which, as noted above, are spaced at intervals approximately ·5 mm. apart, there is a marked concentration of these heavy minerals which include, in order of abundance: black opaque iron ore, green tourmaline and purplish zircon.

The tourmaline which is a constant heavy mineral accessory in the metasediments of the Barrens Belt occurs in grains showing no signs of abrasion. It appears to be constant in its characteristics and to be schorl with strong pleochroism ω = deep green, ε = pale clove-brown and ω = 1·660. Many of the tourmaline grains have a deeper coloured strongly pleochroic rounded central part surrounded by a thin outgrowth of practically non-pleochroic pale green tourmaline—these appear to be original detrital rounded schorl grains with authigenic outgrowths of elbaite. The muscovite quartzites from West Mt. Barren (7482) also show tourmaline with these characteristics.

The zircon is in much smaller grains than the tourmaline, is of the pink or purple variety and shows rounding without any authigenic outgrowths as in the tourmaline.

With an increase in the muscovite content the muscovite quartzites become very slaty as evidenced by specimen 13315 from Pt. Ann. This slaty muscovite quartzite splits readily into laminae 1 mm. or less in thickness and on these cleavages a distinct lineation can be seen. Thin sections cut parallel to the slaty cleavage show that this is due to a noticeable elongation of the mica flakes and a slight elongation of the quartz grains parallel to the lineation. Since the orientation of the specimens is unknown no petrofabric work has been done on these rocks but the slices examined indicate that fabric studies may yield interesting results. The slaty muscovite quartzites of Pt. Ann (as exemplified by 13315) are similar to the muscovite quartzite described above except for their higher muscovite content, their finer grain and the tendency for the quartz to occur in more elongated grains. The heavy accessories are iron ores, tourmaline (again in rounded grains of schorl with irregular colourless outgrowths) and zircon. These slaty quartzites form an intermediate group between the quartzites and quartz-muscovite schists which are decsribed below.

Another variant of the quartzites is a *chlorite quartzite* (24113) from the coast south of Middle Mt. Barren. This rock is a greenish grey quartzite and in it the place of muscovite is taken by a light green pleochroic chlorite. A notable accessory in this rock is a greenish brown tourmaline in grains to 0·25 mm. diameter, —much larger than those noted in the muscovite quartzites.

of quartz in recrystallised lenticular grains and the darker bands are proportionately richer in green chlorite and ilmenite. The yellow anatase noted in specimen 17476 (*see* under (i) above) is present also in these chlorite-bearing schists and, together with ilmenite, is very abundant in 13333 from Point Charles—this latter specimen is from a heavy mineral band in the sediments.

(iii) *Biotite-bearing schists.*

Biotite is a comparatively rare constituent in the schists represented in the collection. The lowest grade rock in which it appears is 13311 from Pt. Ann. This is a silky-lustred, dark grey phyllite which contains a marked development of small biotite flakes which are often arranged normal to the schistosity. The constituents are sericitic muscovite, quartz in elongated grains, brown biotite and comparatively abundant accessory greenish brown tourmaline similar to that occurring in the quartzites described above. The rock is best described as a quartz-biotite-sericite phyllite.

Much higher grade completely recrystallised biotite schists occur in the St. Mary's River approximately 3 miles west of Pt. Ann. Specimen 13326 is an example—it has a schistose structure and a marked development of muscovite plates which are often arranged transversely to the foliation. The constituents, in order of abundance, are greenish brown biotite (in plates averaging 0·7 mm. in length), muscovite (plates averaging 1·5 mm. in length generally growing transverse to the schistosity), smaller grains of quartz, an abundance of small granules of epidote, and several porphyroblasts of clear albite enclosing small biotite flakes and epidote granules. These coarse-grained dark-coloured epidote-muscovite-biotite schists are associated with finer-grained light-coloured schists (13324, 13327) in which there is a much higher proportion of quartz and albite, and biotite becomes a minor constituent. These biotitic muscovite-albite-quartz schists are a meta-arkosic facies of the same group of sediments.

(iv) *Meta-conglomerates.*

Schists containing lenticular sheared pebbles and clearly derived from a conglomerate facies occur between Pt. Ann and Pt. Charles. Specimen 13329 is a silky lustred muscovite schist containing darker coloured sheared pebbles which under the microscope prove to be fine grained quartz-muscovite schist with abundant ilmenite and anatase, and thus similar in all respects to the schists described under (ii) above. In view of the close petrographic similarity between the "pebbles" and the schists with which the meta-conglomerate is associated this appears to be an intra-formational conglomerate.

At Dempster Inlet meta-conglomerates occur interbedded with the schists. Specimen 24112 is typical. It consists of sheared-out pebbles of quartzite in a fine-grained siliceous matrix. The original quartzite pebbles were well rounded and now appear as elongated ellipsoids up to several inches in length. The measurements of one such sheared pebble, 7 cm. x 2 cm. x 1 cm., will indicate the order of the "stretching" that has been effected in this conglomerate. This rock is now a schistose muscovite quartzite.

(v) *Kyanite-bearing schists.*

Kyanite schists have been noted in a number of localities. Specimen 7483 from West Mt. Barren is typical. It is a coarse-textured rock with an abundance of kyanite in stout prisms of the order of 1 to 1½ mm. in length occurring in a granoblastic aggregate of quartz, muscovite, and pale green

chlorite, with accessory opaque iron ores. The kyanites contain many granular iron ore inclusions similar to those in the schists which occur east of the Hamersley Inlet. A collection of the kyanite schists of this area was made by the Government Geologist (Mr. Ellis) who has kindly allowed us to extract the following from the Government Chemist and Mineralogist's report on the material collected :—

" The schists generally consist mainly of muscovite, quartz, and, in some cases, biotite ; small grains of one or more of the following minerals were also present :—magnetite, rutile, ilmenite, limonite, hematite, staurolite, and tourmaline ; the garnet present in one specimen is almandine, in somewhat rounded grains, 1 to 2 mm. Analyses of the kyanite are :—

	A. %	B. %
Al_2O_3	58·87	51·94
SiO_2	34·27	34·63
Fe_2O_3	2·55	7·15
FeO	1·61	3·39
TiO_2	0·02	1·05

A. Better quality kyanite.

B. " Black kyanite " (containing small particles of magnetite and ilmenite)."

(c) *The limestones.*

Limestones are of rare occurrence, the only specimen in the collection being a red marble-breccia (17183) which occurs associated with the quartzites and schists approximately one mile west of the Hamersley Inlet. This rock has a brecciated structure consisting of about equal proportions of angular white fragments and purple-red groundmass, both fragments and groundmass being traversed by narrow veinlets of white carbonate. The white fragments are up to 1 inch diameter and consist entirely of dense dolomite in which the grains average 0·1 mm. diameter. The reddish coloured matrix of the rock is a coarser textured seriate aggregate of dolomite in which the individual grains measure up to 5 mm. diameter. They are dusted with tiny earthy-lustred hematite grains. A little pale brownish green biotite in flakes to 0·3 mm. diameter is dispersed throughout the matrix and there is also a little recrystallised hematite (in small silvery plates which are deep red in transmitted light) and black opaque magnetite. The white veinlets which traverse both the fragments and enclosing matrix are made up of comparatively coarse-grained white dolomite with a minor amount of quartz.

2. *The metasediments of the Mt. Ragged belt.*

Quartz-muscovite schists and quartzites containing variable amounts of muscovite and biotite are the characteristic rocks of this belt. The quartzites are all coarse-grained and completely recrystallised and in this respect resemble the quartzites of the Jimperding Series as exposed in the Toodyay District (Prider, 1944). Andalusite occurs in some quartz-mica schists from Mt. Ragged.

Typical rocks from this belt are :—

(a) *Quartzite* (24483).

A white, coarse, granulose-structured rock, which under the microscope is seen to consist almost entirely of quartz in interlocking grains of the order of 2 to 3 mm. diameter, the only other constituent being a few very small zircons.

(b) *Biotite-muscovite quartzite* (24486).

A white coarse-grained rock with a platy structure. It tends to break into flat sheets because of the parallel orientation of the mica flakes (both biotite and muscovite) which constitute 5% or less of the rock. Under the microscope the rock is a granoblastic aggregate of quartz in grains averaging 1½ mm. diameter. Both muscovite and greenish brown biotite are present, occurring associated together in between the quartz grains or as parallel oriented flakes enclosed in the quartz. Although the mica flakes average 0·3 mm. in length larger muscovite flakes up to 3 mm. diameter are seen in the hand specimen. The only accessory is a few minute colourless zircons.

(c) *Andalusite-quartz-muscovite schist.*

Andalusite-quartz-muscovite schist (24517) from the S.W. part of Mt. Ragged is a white silky-lustred schist with porphyroblastic andalusite prisms up to 1 cm. in length. The rock consists essentially of quartz and muscovite with the andalusite prisms scattered sparsely throughout. Accessory iron ore is present as minute black grains evenly dispersed throughout the rock. This iron ore is not appreciably magnetic and appears therefore to be ilmenite rather than magnetite. The porphyroblastic andalusite is to a large extent replaced by platy muscovite in a similar fashion to the andalusite of the Jimperding Series at Toodyay (Prider, 1944, p. 103) but there is a considerable amount of residual andalusite present.

Another specimen (24518) of andalusite-muscovite schist from Mt. Ragged has, in addition to the development of the andalusite porphyroblasts, an unusual porphyroblastic development of muscovite. The porphyroblastic muscovite plates averaging 5 mm. long x 0·08 mm. thick are arranged in a close-spaced reticulate pattern with the 001 cleavage nearly normal to the schistosity and thus simulate sillimanite needles. No sillimanite has however been detected in this or any other specimen in the collection from the Mt. Ragged belt.

(d) *Garnetiferous biotite-quartz-muscovite schist* (32579).

This specimen comes from the southern end of the Russell Range farther north along the strike of the Mt. Ragged metasediments. It is a white silky-lustred schistose rock with a marked development of black platy biotite porphyroblasts up to 2 mm. diameter. Tiny pink garnet rhombdodecahedra up to 0·3 mm. diameter are sparsely distributed throughout the entire specimen. Under the microscope the structure is strongly schistose and the dominant constituents are quartz (in equidimensional grains averaging 0·15 mm. diameter) and muscovite (in plates to 0·3 mm. long). The biotite porphyroblasts do not appear to have any definite arrangement and they often occur with the basal cleavage at right angles to the schistosity. This biotite is a brownish strongly pleochroic variety and has a poikiloblastic structure enclosing quartz and iron ore grains similar to those occurring in the groundmass. The most abundant accessory is a weakly magnetic black opaque ore (? ilmenite) followed by fairly abundant euhedral tourmaline and rare rounded zircons. The tourmaline is a strongly pleochroic schorl with ϵ = clove brown, ω = very dark green to black, and is always euhedral and therefore does not appear to be detrital tourmaline.

The rocks of the Mt. Ragged belt are metasedimentary schists and quartzites, which in view of the coarse recrystallised nature of the quartzites appear to belong to a higher grade of metamorphism than the rocks of the Barrens belt. A. Gibb Maitland (1924, pp. 5–7) examined the Mt. Ragged and Russell Ranges in 1924 and gives descriptions and chemical analyses of two rocks from Mt. Ragged. The analyses of these two specimens quoted from Maitland (1924, p. 6) are set down in Table I.

TABLE 1.

Analyses of Quartz-muscovite schists from Mt. Ragged.

	A.	B.
SiO_2	92·46	90·46
Al_2O_3	4·11	4·88
Fe_2O_3	1·34	1·47
FeO	0·08	0·10
MnO	0·09	0·15
MgO	0·42	0·42
CaO	*Nil*	0·09
Na_2O	0·04	0·02
K_2O	1·26	1·49
LiO_2	....	*Nil*
H_2O—	0·08	0·04
H_2O+	0·53	0·67
TiO_2	0·11	0·11
P_2O_5	*Nil*	0·05
ZrO_2	trace	..
CO_2	*Nil*	0·07
FeS_2	*Nil*	0·11
	100·52	99·85
Sp.Gr.	2·69	2·69

A. Quartz Sericite Schist, South end of Mt. Ragged.

B. Quartz Sericite Schist, Spring East of Tower Peak, Ragged Range.

Gibb Maitland considered that " the schists seem to be genetically related to plutonic igneous rocks and probably owe their origin to the transmutation of a granite." There can be no doubt however that the rocks of this belt are high grade metasediments and although sillimanite has not been found as yet in them they are, judging from the nature of the quartzites, of sillimanite zone metamorphism.

B. The Greenstones associated with the Gairdner R.-Phillips R. metasediments.

There is no evidence, in the collection examined, of the presence of basic volcanics such as the slightly metamorphosed Older Greenstones (fine-grained greenstones and amphibolites) of the Coolgardie and East Coolgardie Goldfields or of the highly metamorphosed basic volcanics (hornblende schists) of the Yilgarn and Dundas Goldfields. The only rocks in this collection which could be regarded as belonging to the Greenstone phase of the Kalgoorlie-Yilgarn System are hypabyssal in character and are now represented by uralitized quartz dolerites and gabbros. They are indistinguishable petrographically from the basic intrusives of the Younger Greenstones of the East Coolgardie Goldfield. In many ways they are similar to some of the younger Pre-Cambrian dolerites which are intrusive into the Stirling Range beds and which are

described below in section F. The main differences from the Younger Pre-Cambrian basic dyke rocks are in the more extensive uralitization and saussuritization of the older rocks considered in this section and also in the extensive replacement by leucoxene of the accessory skeletal ilmenite in these rocks and the presence in most specimens of evidence of shearing. Specimen **17471** from the Phillips River gorge at $1\frac{1}{2}$ miles south of the point where the old telegraph line crosses the river may be regarded as typical of these uralitized quartz gabbros of the Greenstone group. It is a greenish grey, medium-grained rock in which the sub-ophitic texture can be seen in hand specimen. Microscopic examination shows that it consists essentially of completely uralitised pyroxene and completely saussuritised plagioclase in ophitic relationship, with accessory end-stage quartz and micropegmatite occurring in angular areas up to 2 mm. diameter between the earlier felspar and ferro-magnesian constituents. Characteristic needles of apatite are associated with this end-phase quartz and micropegmatite. Ilmenite is the only other accessory and it is invariably completely leucoxenised. The uralite replacing the original pyroxene plates is a very pale green fibrous variety and there are rare remnants of the original pyroxene. The turbid saussuritic aggregate which completely replaces the original idiomorphic plagioclase consists largely of zoisite and sericite. Although this particular specimen has no shearing structures to obscure the original ophitic relation between the uralitic areas and the saussuritised plagioclase most of the specimens representing this "Greenstone" group show evidence of shearing, some, such as **17468** from the same locality as the type specimen having a marked schistose structure—the occurrence in this rock of angular areas of quartz and micropegmatite with the associated apatite needles is clear evidence of its derivation from the uralitised quartz gabbro.

C. The Gneisses.

As has been pointed out in the first section of this paper gneiss is by far the most widespread type of rock of the Strip. There is considerable mineralogical variation amongst the gneisses but they consist essentially of various granitic gneisses (probably largely granitization products of pre-existing rocks) containing basic bands and lenses, and a subordinate group of paragneisses which are interleaved with them. Many of the granitic gneisses carry hypersthene and show marked affinities with the charnockitic suite.

The gneisses and associated rocks have been classified as follows :—

I. *Granitic and charnockitic gneisses* (quartz-felspar-ferromagnesian bearing gneisses of migmatitic character) which are subdivided firstly on the basis of the ferromagnesian minerals present and then further subdivided according to the nature of the felspars thus :—

- A. Biotite-bearing :—
  1. with plagioclase as the sole felspar,
  2. with potash felspar as the sole felspar :—
     - (a) Containing orthoclase.
     - (b) Containing microcline.
  3. with both plagioclase and potash felspar :—
     - (a) Containing orthoclase.
     - (b) Containing microcline.
- B. Hornblende-bearing (subdivided as in A above).
- C. Biotite-hornblende-bearing (subdivided as in A above).
- D. Hypersthene-biotite-bearing (subdivided as in A above).
- E. Carrying biotite, hornblende and hypersthene (subdivided as in A above).
- F. Garnet-biotite-bearing (subdivided as in A above).
- G. Free from ferromagnesian minerals (subdivided as in A above).

II. *Para-gneiss* :—

A. Alumina-rich gneisses.

B. Calc-silicate gneisses.

III. *Basic lenses* (granulose to gneissose consisting of felspar + femics ± accessory quartz) which are subdivided according to the femic minerals present thus :—

A. With hornblende as the only femic.
   1. Quartz absent.
   2. Quartz present.

B. Containing biotite and hornblende (subdivided as in A above).

C. Containing hornblende and pyroxene—subdivided as in A above and further subdivided according to the nature of the pyroxene :
   (a) hypersthene only,
   (b) clinopyroxene only,
   (c) both ortho- and clino-pyroxene present.

D. Containing biotite, hornblende and pyroxene—subdivided according to presence or absence of quartz and the nature of the pyroxene as in C above.

In the description of the field occurrences and on the accompanying geological map (Plate I), in order to condense the nomenclature of the various gneisses (which can only be described for example by names such as biotite-hornblende-quartz-plagioclase-microperthitic microcline gneiss), the type of gneiss may be expressed by a symbol according to the classification set out above. Thus the symbol (IA3a) signifies a granitic gneiss carrying biotite as the only ferromagnesian and containing both plagioclase and potash felspar and that the potash felspar is orthoclase. Brief descriptions of a typical specimen from each of the groups represented in the collection are set down below. Such chemical analyses as have been made have been, so as possible, of rocks from the one locality rather than from a number of different localities widely scattered along the coast. It was considered that such analyses of rocks from a single locality may be of more use to future investigators (who may decide to do more detailed work on the petrology of the Strip) than analyses of rocks from widely different localities. Most of the type specimens for chemical analysis are from the Point Irby-Cape Riche locality and the results of the chemical analyses made of the gneisses and associated rocks are set down in Tables II, III and IV.

Brief petrographic descriptions of the various gneisses are as follows :—

I. *Granitic gneisses.*

A. *With biotite as the only femic mineral.*

This group is by far the best represented in the collection and 47 of the 92 specimens of the granitic gneiss that were examined microscopically fall into this group. Of the biotite-bearing granitic gneisses those containing both plagioclase and potash felspar are predominant (40 specimens of a total of 47).

IA1 :—*Biotite-quartz-plagioclase gneiss* is represented by two specimens only of which 23268 from approximately 1/3-mile N.N.W. from the main point at Point Hillier has been chosen as the type specimen. This a leucocratic, even-medium grained, gneissic structured rock which in hand-specimen consists essentially of a fine grained quartzose matrix which encloses milky-white prisms of felspar up to 2 mm. diameter. The gneissic structure is imparted by thin layers of light greenish brown mica and there is a fairly well developed lineation on the foliation planes due to the elongation of the mica plates.

Under the microscope the texture is granoblastic gneissic and the constituent minerals in order of abundance are quartz, saussuritised plagioclase, chloritised biotite associated with a little muscovite, and rare accessory zircon, apatite and opaque iron ore. The quartz, which shows marked undulose extinction and crushing, in a direction parallel to the gneissic foliation, is in large granoblastic aggregates which enclose isolated plagioclase crystals and chloritised biotite flakes. The plagioclase is all rather turbid through alteration to fine granular zoisite and flaky sericite but this alteration is not so intense as to obscure the lamellar twinning. The plagioclase appears to be uniform in composition and is albite-oligoclase with refractive index less than Canada Balsam and maximum extinction of 14° in sections normal to 010. The biotite which is in ragged pale greenish plates has been completely replaced by chlorite. Potash felspar is completely absent.

TABLE II.

Acid gneisses from the South Coast strip, W.A.

	A.	B.	C.	D.	E.
SiO_2	74·18	68·40	63·22	66·94	61·04
Al_2O_3	14·73	16·53	14·63	14·22	18·45
Fe_2O_3	0·60	0·74	2·91	0·30	0·61
FeO	0·79	2·29	9·23	8·92	8·90
MnO	*Nil*	Tr.	0·58	0·23	0·09
MgO	0·18	1·46	2·32	1·42	3·11
CaO	1·84	3·08	2·92	2·20	1·23
Na_2O	2·64	3·74	1·46	0·74	1·20
K_2O	4·52	2·15	0·85	3·29	2·64
H_2O+	0·34	0·32	0·75	0·72	1·34
H_2O-	0·18	0·46	*Nil*	0·03	0·17
TiO_2	0·19	0·44	1·06	1·01	1·18
P_2O_5	Tr.	0·15	Tr.	0·28	0·22
CO_2	*Nil*	*Nil*	*Nil*	*Nil*	0·50
FeS_2	....	....	....	....	0·15
Total	100·19	99·78	99·93	100·30	100·83
Norms :					
Q	36·96	29·10	35·40	37·32	30·88
or	26·69	12·23	5·00	19·46	15·58
ab	22·53	31·44	12·58	6·29	10·17
an	9·17	14·46	14·46	8·90	4·70
C	2·04	2·86	5·92	6·12	11·90
hy	0·93	6·64	19·53	18·38	21·82
il	0·46	0·76	2·13	1·98	2·23
mg	0·93	0·93	4·18	0·46	0·88
ap	....	0·34	....	0·67	0·49
py	....	....	....	....	0·15
C.I.P.W. Classification	I.3.2.3.	I.4.3.4.	II.3.3.4.	II.3.3.2.	II.3.2.3.

A. Biotite-quartz-andesine-orthoclase gneiss (IA 3a) (Specimen 16577 from Cape Riche, W.A.) *Anal.* W. H. Herdsman.

B. Biotite-hypersthene-quartz-oligoclase-orthoclase gneiss (ID3a) (Specimen 20016 from Point Irby, W.A.) *Anal.* W. H. Herdsman.

C. Garnet-biotite-quartz-plagioclase gneiss (IF1) (Specimen 16585 from Cape Riche, W.A.) *Anal.* W. H. Herdsman.

D. Garnet-biotite-quartz-andesine-microcline gneiss (IF3b) (Specimen 23282 from Point Nuyts, W.A.) *Anal.* W. H. Herdsman.

E. Biotite-quartz-plagioclase-cordierite-garnet granulite (IIA) (Specimen 7838 from Whale Head Rock, Albany, W.A., quoted from Simpson, 1951, p. 105).

IA2 :—*Biotite-quartz-microcline gneiss* (24495 from Point Malcolm). This is a leucocratic even-fine grained gneiss (average grain size 0·2 mm.) with thin (3 mm. wide) bands of slightly coarser textured quartz-microcline aplite running parallel to the gneissic structure in the fine grained biotitic gneiss. Quartz, felspar and biotite are the only minerals recognisable in hand specimen. In thin section the rock has an even granoblastic texture with a foliation due to the parallel orientation of the biotite flakes. The average grain size is 0·2 mm. and the constituents in order of abundance are microcline, quartz and biotite with accessory muscovite, zircon and iron ore. The microcline all shows cross-hatched twinning and is microperthitic, —very fine in the biotitic part of the rock and somewhat coarser in the aplitic seams where the microcline grains are up to 1 mm. diameter. Biotite, which is present to the extent of approximately 5 per cent., is a greenish brown variety. Muscovite is rare as are the other accessories zircon (in tiny euhedra) and iron ore.

Gneisses of this group, containing microcline as the only felspar, are rare and are represented by 3 specimens only from the collection examined.

IA3 :—*Biotite-quartz-plagioclase-alkali felspar gneiss.* This type is by far the most abundant of the gneisses represented in the collection and there is very considerable variation within the group from fine to coarse textured gneisses and from varieties containing very little biotite to those containing appreciable amounts of biotite and from rocks in which the alkali felspar is orthoclase to those in which it is microcline.

Specimen 16577 (from the north side of the mouth of the Eyre River at Cape Riche is an example of the fine-grained, biotite-poor, orthoclase-bearing variety (IA3a) which has been chemically analysed. It is a white, even-textured, fine-grained gneiss with a very small proportion of dark-coloured minerals (biotite + magnetite together amounting to approximately 1% to 2% of the rock). The texture is uniform granoblastic gneissic and the minerals present are microperthitic orthoclase, andesine, quartz, a little myrmekite, biotite and magnetite. The orthoclase which is microperthitic, untwinned, and has straight extinction in 001 cleavage fragments, is the predominant felspar. The plagioclase is a clear andesine ($Ab_{65}An_{35}$) with γ greater than 1·553, optical character negative and maximum extinction of 17°. The biotite is a deep reddish brown variety and the only accessories are magnetite and very rare zircon. The most unusual feature of this type of gneiss is the association of orthoclase and plagioclase as basic as andesine. Wilson (1947, p.207) has noted this association in the acid charnockites of the Musgrave Ranges of Central Australia and he informs us that as a result of further work on these rocks this association appears to be characteristic of the charnockitic gneisses generally. Although the Cape Riche specimen described above does not carry hypersthene it is associated with hypersthene-bearing gneisses (16584, 16588) of group ID3 and basic charnockites (16582) of group IIIE1c and may be considered a member of the charnockitic gneisses. A chemical analysis of this rock is given in Column A of Table II and this analysis serves to emphasise the association of alkali felspar with andesine in this group.

Specimen 20037 (from approximately 1 mile S.W. of the mouth of Torbay Inlet) is typical of the *microcline-bearing* members of this group (IA3b). This rock is a light-coloured gneiss with a well developed lineation. It is much richer in biotite than the orthoclase-bearing rock from Cape Riche. The texture is even grained granoblastic gneissic and the constituent minerals in order of abundance are microcline, quartz, oligoclase and biotite with accessory

apatite, zircon and opaque iron ore. The microcline is in xenoblastic grains to $1\frac{1}{2}$ mm. diameter, is water-clear, slightly microperthitic, and carries rounded quartz inclusions averaging $\frac{1}{4}$ mm. diameter. Its water-clear character is in marked contrast to the somewhat altered oligoclase which is invariably turbid through slight saussuritization—this is characteristic of all the microcline-bearing gneisses of group IA3b and, together with the enclosures in the microcline suggest that is has been introduced at a late stage in the formation of the rock. The oligoclase is well twinned, slightly saussuritised, has practically straight extinction in sections normal to 010 and $(\pm)2V$ near 90° and is therefore close to $Ab_{80}An_{20}$. The biotite, in well oriented ragged plates to 0·8 mm. diameter, is brownish in colour and in places is replaced along the cleavages by pale green chlorite. This replacement of biotite by chlorite is common in this group and in such instances there is generally a development of sagenitic rutile inclusions in the resultant chlorite and moreover a tendency for epidote grains to be associated with the chloritised biotite. The quartz of this rock shows slight strain effects, is invariably xenoblastic and occurs in two habits : (a) as rounded inclusions in the water-clear microcline and (b) as larger irregular shaped grains, elongated parallel to the foliation, which sometimes enclose biotite and oligoclase. This latter type of quartz appears to have been introduced at about the same time as the microcline. This type of gneiss with the rounded quartz inclusions in microcline is most probably a granitization product from an earlier arkosic sediment.

B. *With hornblende as the only femic mineral.*

Gneisses of this group are rare and are represented by a single specimen (20031 from near the mouth of the Cordinerup River) in the collection examined. This specimen belongs to group IB1 with hornblende, plagioclase, and quartz as essential constituents. It is an even-textured medium-grained rock with a gneissic structure due to the tendency of the black coloured amphibole to occur in bands. The microstructure is granoblastic and gneissic due to the hornblendes being clustered into lenticles rather than to an actual parallel orientation of the hornblende. The essential constituents are plagioclase, quartz, and hornblende, all of which are xenoblastic. The plagioclase appears to be uniform in nature, is well twinned, shows patchy turbidity although on the whole it is unaltered, and is acid andesine ($Ab_{67}An_{33}$). The amphibole is in stout xenoblastic prisms up to $1\frac{1}{2}$ mm. long enclosing irregular shaped quartz grains—it is a deep green hornblende with X pale yellow-green, Y dark yellow-green, Z dark green and forms approximately 10% of the rock. Quartz is present to the extent of approximately 40% in very irregular shaped xenoblastic grains to $2\frac{1}{2}$ mm. diameter which are often elongate parallel to the foliation. In general it is free from any strain effects. The accessories are magnetite (often rimmed with sphene), sphene, apatite and rare zircons.

C. *Biotite-hornblende bearing gneisses.*

All the gneisses carrying both biotite and hornblende contain both plagioclase and potash felspar, the latter being orthoclase, and so fall into the group IC3a. Some of the intrusive granites, such as the Porongorups granite, carry the same mineralogical assemblage and moreover have a primary gneissic structure due to flowage and are very difficult to differentiate from the older gneisses in hand specimen alone. Generally however the intrusive granites are porphyritic and the only gneisses that have been included in this group (IC3a) are those that are equigranular granulose gneissic in structure.

IC3a :—*Biotite-hornblende-quartz-plagioclase-orthoclase gneiss* is best represented by specimen 24464 from Mt. Le Grand. This is a granulose-structured slightly gneissic rock of medium to coarse texture. The constituents in order of abundance are orthoclase, oligoclase, quartz, biotite, and hornblende with accessory apatite, euhedral zircon, and opaque iron ore. Both felspars are water clear and there is an extensive development of myrmekite where they are in contact. The orthoclase is untwinned and slightly microperthitic. The plagioclase shows lamellar twinning and is oligoclase-andesine close to $Ab_{70}An_{30}$. The biotite is a dark brownish variety, pleochroic from yellow to dark slightly reddish brown, and occurs in plates up to $1\frac{1}{2}$ mm. diameter which tend to be clustered together. The hornblende and the more abundant accessory, apatite, are closely associated with these biotitic clots. The hornblende is a dark greenish variety with pleochroism X brownish green, Y brownish green, Z dark green.

D. *Hypersthene-biotite bearing gneisses.*

Rocks of this group are equigranular granulose with poorly developed gneissose structure. They carry both plagioclase and orthoclase and are free from microcline and fall into the classification ID3a, a group which may best be described as acid charnockites.

ID3a :—*Biotite-hypersthene-quartz-plagioclase-orthoclase gneiss* (acid charnockite). Specimen 20016 from Point Irby has been chosen as typical and a chemical analysis of this rock is given in Table II. It is a granulose rock with a gneissic structure which has, on freshly broken surfaces, the typical greasy lustre of the charnockites. Under the microscope the texture is granoblastic and the minerals noted, in order of abundance, were plagioclase, quartz, orthoclase, hypersthene, biotite, magnetite, and apatite. The plagioclase is in irregular shaped elongated xenoblasts to 2 mm. long and for the most part is water-clear, untwinned and carries antiperthitic inclusions. Where it is in contact with the orthoclase there is generally a development of myrmekite. Some of the plagioclase shows fine lamellar twinning and strain effects in the bending of the twin lamellae. The extinction in sections normal to 010 is up to 6° and the refractive index is slightly greater than $1 \cdot 544$ indicating oligoclase ($Ab_{75}An_{25}$). The orthoclase which is subordinate to the oligoclase, is water-clear, untwinned and microperthitic. Most of the quartz, which occurs in irregular shaped elongated grains up to 3mm. long, shows slight undulose extinction. The hypersthene is in irregular-shaped prisms to $1\frac{1}{2}$ mm. long showing considerable alteration to serpentine along the margins and transverse cracks. The hypersthene prisms are arranged with their long axes parallel to the foliation and they tend to occur in clots associated with deep reddish brown biotite and the accessory apatite and magnetite tend to be concentrated in the vicinity of the biotite-hypersthene aggregates. The biotite in all the rocks of this group is a deep reddish brown practically uniaxial variety. Clinopyroxene is absent.

In view of the greasy lustre of the hand specimens of rocks of this group they would appear to contain cordierite. Careful search has however failed to prove the presence of cordierite the search for which is rendered difficult because of the absence of zircon which causes the development of the yellow pleochroic haloes which are so useful in the diagnosis of cordierite. Looking at the analysis of this rock (analysis B in Table II) we see that so far as the iron-magnesium bearing normative minerals are concerned we have $0 \cdot 93\%$ of magnetite, $0 \cdot 76\%$ of ilmenite and $6 \cdot 64\%$ of hypersthene. These amounts

are covered by the modal hypersthene, biotite and iron ore present leaving no iron or magnesia for cordierite. In spite therefore of the typical greasy lustre we can be assured that in this particular specimen at least, cordierite is not developed.

E. *Biotite-hornblende-hypersthene bearing gneisses.*

These are similar to ID3a above with the addition of small amounts of dark green hornblende (20020 from Point Irby).

F. *Garnet-biotite-bearing gneisses.*

The garnetiferous gneisses fall into two sub-groups—the most abundant being characterised by the presence of both plagioclase and microcline (IF3b) and the less abundant is that group containing plagioclase only (IF1) or with potash felspar only in accessory quantity.

IF1 :—*Garnet-biotite-quartz-plagioclase gneiss* (16585 from Cape Riche—*see* chemical analysis C in Table II). This is an even medium-grained, gneissic-structured rock consisting of white quartzo-felspathic bands (1 cm. wide), alternating with narrow darker coloured biotitic bands (2 mm. wide) and mesocratic bands to 3 cm. wide. Pink garnet is most abundantly developed in the biotitic bands but is not confined to these bands but is dispersed throughout the specimen even in the quartzo-felspathic bands. Under the microscope the texture is granoblastic and the minerals in order of abundance are plagioclase and quartz in approximately equal proportions, garnet, biotite, orthoclase, iron ore, and zircon. The biotite is in well developed flakes and the garnet is idioblastic but the other constituents are xenoblastic. Some of the plagioclase is sericitised and turbid but on the whole is water-clear. It is well twinned and many grains have a coarse antiperthitic structure. The plagioclase appears to be of more than one variety some having refractive indices greater than 1·55, others less. The coarse antiperthitic inclusions appear to be the result of replacement of the plagioclase rather than due to exsolution. In places particularly in the vicinity of rounded quartz grains and on the margins of the antiperthitic plagioclase there is a growth of anhedral orthoclase and one field (Plate II, fig. 2) shows a rounded quartz enclosed in orthoclase which in turn is enclosed in antiperthite. These rounded quartz grains which have been noted in other gneisses (*see* IA3b above) are probably relicts of earlier water-worn grains and an indication that these gneisses were originally sediments. The only orthoclase present in this rock is in the anti-perthite and the small amount replacing the plagioclase. Quartz occurs in two habits—as large xenoblastic grains elongated parallel to the foliation and as rounded grains rimmed with orthoclase in the plagioclase. The garnet is a pink almandine in idioblasts and skeletal crystals up to 2 mm. diameter often with diblastic inclusions of quartz and biotite. It has irregular cracks along which it is being replaced by bright green very weakly birefringent chlorite. The biotite, which is a deep reddish brown variety similar to that noted in the hypersthene-bearing gneisses (ID), tends to be concentrated in schistose structured bands within which the biotite plates averaging 0·6 mm. diameter are oriented parallel to the length of the band. The accessories are magnetite (fairly abundant) and small rounded zircons.

A chemical analysis of this rock is set down in column C, Table II from which it will be seen that there is nearly 6% of normative corundum (due in large part to the modal garnet). This, considered in conjunction with the rounded quartz grains, the rounded zircons and the tendency for the biotite to occur in narrow bands (? the original sedimentary bedding) is suggestive of a metasedimentary origin for this rock.

IF3b :—*Garnet-biotite-quartz-plagioclase-microcline gneiss* (23282 from Point Nuyts—*see* chemical analysis D in Table II). This is a greyish, medium to coarse, granulose-structured rock with very poorly developed gneissic structure due to the presence of coarse-textured white lensing bands and segregations of quartzo-felspathic material. Garnet is not at first evident in hand specimen but on careful examination it can be seen scattered sparsely throughout the rock.

Under the microscope the texture is coarse granoblastic gneissic there being a tendency for the biotite plates to be in parallel orientation and for the quartz to occur in xenoblastic forms elongate parallel to this direction. The constituents in order of abundance are microcline, quartz, plagioclase, garnet, biotite, sericite, magnetite, and rare zircon and apatite. This rock, except for its more granulose structure, and the garnet, is similar to those of group IA3b. The microcline is clear, not noticeably microperthitic, and carries quartz inclusions and around its margins has a considerable amount of sericitic material which is largely the product of alteration of the plagioclase. The plagioclase shows a variable degree of sericitisation—this sericite is much coarser textured than normally and has evidently been somewhat recrystallised leaving the plagioclase water-clear. The plagioclase has refractive index greater than quartz and extinction up to 20° in sections normal to 010 and is andesine close to $Ab_{60}An_{40}$. The biotite is pale brown in colour and is characterised by sagenitic rutile inclusions it has a " bleached " appearance and is considerably altered and generally surrounded by a zone of sericitic material. The garnet also is considerably altered to brightly polarising sericitic material along the numerous irregular cracks. The garnet is in irregularly cracked idioblasts up to $1\frac{1}{2}$ mm. diameter which are confined to the biotitic parts of the rock. The accessories which are present in very small amounts only include magnetite (with a narrow rim of sphene), zircon and apatite. The felspathic segregations and seams up to 1 cm. wide occurring in the hand specimen are composed mainly of microcline.

An analysis of this rock, one of the few specimens available from the western end of the area examined, is set down in Table II where it may be compared with the garnetiferous gneiss of group IF1 described above. The analyses of these two rocks are very similar except for the potash content, the higher potash of the microcline-bearing gneiss being due to the presence of abundant microcline and secondary sericite in the rock from Point Nuyts. In view of the considerably sericitised nature of the specimen the presence of 6% of normative corundum in this latter specimen does not perhaps have the same significance as in the garnet-plagioclase gneiss of group IF1. At the same time it has the rounded quartz enclosures in the felspars which suggest a metasedimentary origin evidently it has been subjected to a higher degree of potash metasomatism than the garnet gneiss from Cape Riche (IF1).

G. *Gneisses free from ferromagnesians.*

These are white to cream coloured with a granulose structure and contain femic minerals only in accessory amounts. A typical specimen is a quartz-plagioclase-microcline granulite (24472) from Duke of Orleans Bay which is interbedded with a biotitic microcline-bearing gneiss of group IA3b. It is a pinkish-white, medium-grained, granulose rock with very rare dark-coloured small biotite flakes. Under the microscope the texture is even-grained granoblastic and the constituents are water-clear microcline, turbid sericitised plagioclase, and quartz with brownish biotite present in accessory amount only. Except for the extremely small amount of biotite this rock is similar to those of group IA3b.

II. *Para-Gneisses.*

Although many of the gneisses in group I above were probably of metasedimentary origin they have been granitised and migmatised and have been considered apart from the para-gneisses of more evident metasedimentary origin. As these para-gneisses occur interbedded with the "granitic" gneisses described above it is evident that they represent residuals of the original sedimentary terrain which have escaped the thorough granitization experienced by the rocks of Group I that have been previously described. For convenience of description the para-gneisses have been subdivided into two groups :

A. The alumina-rich gneisses.

B. The calc-silicate gneisses.

These rocks are poorly represented in the collection and the best examples come from Whale Head Rock at Albany and from West Cape Howe.

A. *The alumina-rich para-gneisses.*

Rocks of this group include biotite-garnet-cordierite granulites (*e.g.*, 7838 from Whale Head Rock, Albany) and biotite-garnet-sillimanite-cordierite gneisses (*e.g.*, 20044 from West Cape Howe). The late R. W. Fletcher, in an unpublished MSS. "The metamorphic rocks of the Albany District," described the Whale Head rock and recognised its metasedimentary origin. An analysis of this rock is available and is set down in Table III and a description of the specimen is as follows :—

No. 7838 : Biotite-garnet-cordierite granulite. This is a dark greyish, fine-grained granulose structured rock with idioblastic red garnets up to 5 mm. diameter scattered irregularly throughout. The fine-grained granulose matrix of the rock has the typical greasy lustre of the cordierite-bearing gneisses and

is flecked by innumerable tiny black biotite flakes. Some bands in the rock are lighter in colour due to the presence of a greater proportion of quartz and absence of biotite. The light coloured bands, consisting of garnet, plagioclase, and quartz with minor amounts of cordierite, have a gneissic structure as the tiny pink garnets tend to be concentrated into bands. Under the microscope the structure is granoblastic, even-grained—the average grain size being 0·5 mm.—and the constituent minerals in order of abundance are cordierite, quartz, biotite, plagioclase, garnet, and accessory amounts of magnetite, sillimanite, green spinel and zircon. The cordierite is in equant grains which, because of the extensive alteration along the margins and irregular cracks to fine-grained pinite and the presence of yellow pleochroic haloes about tiny radioactive (? zircon) inclusions, is easily distinguishable in this rock from the water-clear quartz and twinned plagioclase. The cordierite is an iron-rich optically negative variety with (-) 2V approximately 85°. It encloses flakes of biotite, occasional rounded quartz grains, and very rare small sillimanite prisms and associated tiny green spinel grains. The quartz is xenoblastic occurring in the granoblastic aggregate of quartz, cordierite and plagioclase, and as inclusions in cordierite and garnet. Some of the large quartz grains have innumerable hairlike and tiny prismatic inclusions of (?) rutile oriented parallel to their *c*-axes. The plagioclase is a water-clear, well twinned optically negative oligoclase-andesine with refractive index slightly greater than 1·544, in equidimensional grains which are more abundant in the lighter-coloured bands. The biotite, which is confined to the darker-coloured bands, is a deep reddish brown variety. The garnet is a pink almandine in irregular-shaped grains often poikiloblastically enclosing quartz and magnetite grains. The most abundant of the accessories is black opaque magnetite.

The metasedimentary origin of this rock is evident from the variation in the mineralogy of the different bands as follows :—

1. Garnet + quartz (with minor amounts of cordierite and plagioclase).

2. Plagioclase + quartz (with minor amounts of cordierite).

3. Quartz + cordierite + biotite (with minor amounts of garnet and plagioclase).

The bulk chemical composition of the rock supports the metasedimentary origin. An analysis of this rock is set down in Table III and its main feature is the abundance of alumina which yields 11·9% of normative corundum. In composition it closely resembles the metasedimentary cordierite-garnet gneisses of Antarctica and garnet-sillimanite-cordierite gneisses of the Willyama Series of Broken Hill, N.S.W.

Specimen 20044 from West Cape Howe is very similar to the Whale Head rock just described except that it contains a much higher proportion of prismatic sillimanite and reddish brown biotite and the cordierite is almost completely pinitised.

TABLE III.

Biotite-cordierite-garnet granulite.

	A.	B.	C.	D.
SiO_2	61·04	60·93	62·16	63·22
Al_2O_3	18·45	18·09	19·57	14·63
Fe_2O_3	0·61	1·88	0·80	2·91
FeO	8·90	5·55	7·38	9·23
MnO	0·09	0·14	0·26	0·58
MgO	3·11	4·54	2·12	2·32
CaO	1·23	0·90	2·18	2·92
Na_2O	1·20	1·78	1·97	1·46
K_2O	2·64	3·89	2·45	0·85
H_2O+	1·34	1·15	0·62	0·75
H_2O-	0·17	0·14	0·08	*Nil*
TiO_2	1·18	1·07	0·70	1·06
CO_2	0·50	....	0·02	*Nil*
P_2O_5	0·22	Tr.	0·07	Tr.
FeS_2	0·15	....	....	....
Total	100·83	100·08*	100·41†	99·93

* Includes NiO, CoO = 0· 2.
† Includes BaO = 0·03.

Norm :

	A.	B.	C.	D.
Q	30·88	....	....	35·40
or	15·58	....	....	5·00
ab	10·17	....	....	12·58
an	4·70	....	....	14·46
C	11·90	....	....	5·92
hy	21·82	....	....	19·53
mt	0·88	....	....	4·18
il	2·23	....	....	2·12
py	0·15	....	....	....
ap	0·49	....	....	....
C.I.P.W. Classification	II.3.2.3.			II.3.3.1.

A. Biotite-garnet-cordierite granulite (Specimen No. 7838, Albany, W.A., quoted from Simpson, 1951, p. 105).

B. Cordierite-garnet gneiss, Adelie Land, Antarctica (Stillwell, 1918, p. 152).

C. Garnet-sillimanite-cordierite gneiss, Broken Hill, N.S.W. (Andrews, 1922, p. 397).

D. Garnet-biotite-quartz-plagioclase gneiss (16585, Cape Riche, W.A., quoted from Table II. in this paper).

B. *Calc-silicate rocks.*

These vary from granulitic to schistose in structure and a number of different mineral associations have been noted. The following specimens illustrate the nature of this variation :—

(i) *Garnet-epidote granulite* (16581 from " basic lens in gneiss " approximately 1 mile west of the Point at Cape Riche). This is a heavy, dense, fine even-grained, dark greenish grey rock with no trace of banded structure. Under the microscope it is a granulose aggregate of clove-brown grossularite (40%) in irregular-shaped isotropic grains averaging 0·25 mm. diameter, and epidote with minor amounts of bright green chlorite and accessory black opaque iron ore. The epidote (50% of the rock) is in part brightly polarising pistachite and in part zoisite and occurs in fine granular aggregates replacing a mineral (? basic plagioclase) which occurs in equidimensional prisms of the order of 0·3 mm. diameter. The bright green weakly birefringent chlorite (10%) is also in aggregates replacing an equidimensional to prismatic mineral (? pyroxene) of similar size.

A closely related specimen is Geol. Surv. West. Aust. specimen 2/2630 from Goose Island Bay, Middle Island, Recherche Archipelago. This is a mottled pink and yellowish green coloured fine-grained granulite consisting of grossularite, epidote and diopside.

(ii) *Garnet-pyroxene-quartz-plagioclase-cordierite granulite* (7836 from Whale Head Rock, Albany). This is a fine-grained hornfelsic rock which occurs associated with the garnet-cordierite granulite described in IIA above. It has a banded structure which is not at first evident in hand specimen but which shows clearly in thin section. The texture is fine-grained granulitic the grain size of all constituents being uniform and averaging 0·1 mm. The bands, which are of the order of 1 cm. wide are all similar in texture but differ mineralogically consisting of the following associations :—

1. Quartz-almandine-reddish brown biotite-cordierite.
2. Quartz-almandine-hypersthene-cordierite.
3. Quartz-hypersthene-cordierite-magnetite.
4. Quartz-cordierite-hypersthene-bluish green hornblende.
5. Quartz-cordierite-plagioclase-diopside-magnetite.
6. Quartz-cordierite-plagioclase-diopside-garnet-magnetite.

Of these bands the associations 1–4 are similar to those in IIA above and are derived from aluminous sediments whereas associations 5 and 6 represent more calcareous sediments.

(iii) *Quartz-plagioclase-hornblende-biotite schist* (20045 from Forsyth Bluff, West Cape Howe). A fine-grained, uniform-textured, dark greyish, schistose rock in which the only recognisable mineral is biotite on the rock cleavage surfaces. In slices cut across the schistosity this rock has a well developed schistose structure the constituents in order of abundance being biotite, quartz, plagioclase, and hornblende, with accessory black opaque iron ore and rare apatite. There is a tendency also to a banded structure in the distribution of the hornblende. The biotite is strongly pleochroic from yellow to brown and is in flakes averaging 0·3 mm. long x 0·05 mm. thick. The hornblende is bluish green with X pale yellow-green, Y brownish green, Z deep bluish green and occurs in prisms up to 0·5 mm. long. The quartz and plagioclase are in equidimensional grains averaging 0·08 mm. diameter forming a granulitic groundmass, the plagioclase being water-clear (or carrying occasional granules of zoisite) and almost free from twinning but with a higher refractive index than the quartz. The field notes regarding this specimen indicate that it " apparently invades the garnet granulite " (20044—the sillimanite-garnet-biotite-cordierite granulite—mentioned under IIA above), but from the microscopic examination of this specimen it appears to be of metasedimentary origin.

III. *Basic lenses in the gneiss.*

The rocks of this group occur as dark coloured bands or lenses in the acidic gneisses described in I above. They are all characterised by granulose or granulose-gneissic structure but there is very considerable variation in the mineralogical assemblages present and for petrographic purposes they have been subdivided, as shown in the tabulated statement at the beginning of the section on the gneisses, on the basis of (1) the nature of the ferromagnesians, (2) the presence or absence of quartz, and (3) the nature of the pyroxene.

TABLE IV.

Basic bands in the acid gneisses.

	A	*B*	*C*	*D*	*E*	*F*
SiO_2	50·02	48·14	49·99	46·76	47·88	49·05
Al_2O_3	12·98	14·72	18·35	17·94	14·22	15·03
Fe_2O_3	2·75	1·93	2·15	3·16	1·73	3·16
FeO	12·16	12·92	5·97	8·78	12·36	9·08
MnO	0·29	0·24	0·14	0·18	....	0·09
MgO	6·16	6·78	6·19	6·84	6·35	6·96
CaO	10·13	10·53	10·39	10·22	10·23	10·47
Na_2O	2·04	2·26	3·79	2·97	2·47	1·70
K_2O	0·44	0·35	0·91	1·46	0·51	0·95
H_2O+	1·72	0·68	0·92	0·64	0·23	1·43
H_2O-	0·03	*Nil*	0·28	0·04	0·07	0·25
TiO_2	1·42	1·44	0·87	0·93	2·95	1·07
P_2O_5	0·20	0·19	0·30	0·23	0·40	0·08
CO_2	0·06	Tr.	*Nil*	*Nil*	*Nil*	....
FeS_2	0·06	....	0·09	....	....	0·13
	100·46	100·18	100·48*	100·15	99·71**	99·45

* Includes Cl 0·12 ; Cr_2O_3 0·05 ; V_2O_3 Tr. ; F *Nil.*

** Includes other constituents amounting to 0·16%.

Norms.						
Q	2·99	....	....	....	....	1·98
or	2·62	1·67	5·56	8·90	2·78	5·56
ab	17·26	18·86	29·34	17·29	20·96	14·15
an	24·96	29·19	30·86	30·86	26·13	30·58
so	....	....	1·08	...	...	....
ne	...	....	....	4·26	...	....
di	19·98	18·50	15·08	15·46	18·40	16·68
hy	23·66	17·84	....	....	17·91	21·58
ol	...	7·33	11·63	15·82	3·86	....
il	2·69	2·74	1·67	1·82	5·62	2·13
mg	3·98	2·78	3·02	4·64	2·55	4·64
py	0·06	....	0·09	....	....	0·13
ap	0·46	0·34	0·67	0·34	1·01	0·34
C.I.P.W. Classification ...	III.5.4.3.	III.5.4.3.	II.5.3.4.	II.5.4.3.	III.5.4.3.	III.5.4.3.

A. Quartz-hornblende-plagioclase gneiss (IIIA 2) from Lower Pallinup River (Geol. Surv. West. Aust. specimen 1/3665, "Gneissic quartz epidiorite," quoted from Govt. Chemist West Aust. Ann. Rept. for 1925, p. 9).

B. Plagioclase-hornblende-pyroxene granulite (IIIC1c) (specimen 20015 from Point Irby, W.A.) *Anal.* W. H. Herdsman.

C. Biotite-hornblende-pyroxene-plagioclase granulite (IIID1b) (Cape Riche, W.A., quoted from Geol. Surv. West. Aust., Ann. Rept. for 1948, p. 33).

D. Biotite-hornblende-pyroxene-plagioclase granulite (IIID1c) (specimen 16582 from Cape Riche, W.A.) *Anal.* W. H. Herdsman.

E. Plagioclase-hornblende-pyroxene granulite, Bunker Bay (near Cape Naturaliste, W.A.) (quoted from Prider, 1945, p. 161) for comparison with B.

F. Quartz-plagioclase amphibolite, Toodyay, W.A. (quoted from Prider, 1944, p. 105) for comparison with A.

A. *With hornblende as the only ferromagnesian.*

All the specimens examined which belong to this group are characterised the the presence of quartz, *i.e.*, belong to the group IIIA2.

IIIA2 :—*Quartz-andesine-hornblende gneiss* (32613 = G.S.W.A. No. 1/3665 from the Lower Pallinup River—see Maitland, 1924, p. 6). This is a medium-grained, dark grey to black, schistose to gneissic rock consisting of approximately equal proportions of light and dark coloured minerals which tend to occur in alternating bands of the order of 1 mm. wide. The constituents visible under the microscope, in order of abundance, are hornblende, plagioclase, quartz, sphene, and apatite. The hornblende is in stout prisms to 2 mm. long oriented with *c* in the plane of schistosity, but there does not appear to be any preferred direction for *c* within this plane as there is no orientation of the hornblende prisms visible on the foliation planes and a section of this rock normal to the foliation shows both long and transverse sections of hornblende (the transverse sections generally have *b* lying in the foliation plane). The hornblende is an optically negative, brownish green, strongly pleochroic variety with X yellow green, Y brownish green, Z deep bluish green and $Z \wedge c = 25°$. The plagioclase is water-clear andesine ($Ab_{65}An_{35}$), generally free from twinning and shows slight normal transitional zoning. Quartz is in equidimensional grains averaging 0·2 mm. diameter associated with the plagioclase and more rarely occurring as inclusions in the hornblende. Sphene in grains to 0·3 mm. diameter, a few of which contain a central small magnetite inclusion, is an abundant accessory. The sphene grains tend to occur in clusters and most probably represent original large ilmenite grains. Apatite in small stout prisms is rare.

There are no traces of original structures present in this rock which yield any information concerning its origin. It is very similar to the quartz-plagioclase amphibolites which occur as lenses in the Archaeozoic gneisses at Toodyay (Prider, 1944, p. 119). An analysis of the Lower Pallinup rock described above is set down in Table IV, column A, and for comparison the analysis of the similar rock from Toodyay is recorded in column F. Prider (1944, p. 121) has drawn attention to the close similarity in composition between the Toodyay amphibolite and quartz dolerite and considers the amphibolites to be of meta-igneous origin. The Lower Pallinup rock in its lower alumina and higher iron content is still closer to quartz dolerite in composition than the Toodyay amphibolite.

B. *Containing both biotite and hornblende.*

IIIB1 :—*Plagioclase-biotite-hornblende gneiss* (23272 from Point Hillier). An even fine-grained, dark grey to black, slightly gneissic rock, uniform in character throughout except for several thin (1 mm.) felspathic bands and porphyroblasts. Under the microscope the rock has an even-grained granoblastic gneissic structure and consists, in order of abundance, of hornblende, plagioclase, biotite, iron ore, and apatite. The hornblende and biotite are in sub-parallel orientation and the iron ore grains tend to be elongated in the same direction. The hornblende, in xenoblastic prisms averaging 0·3 mm. long, is a brownish green variety with X pale yellowish green, Y brownish green, Z slightly bluish green and absorption $X < Y \geqslant Z$, $Z \wedge c = 20°$. The biotite is pleochroic from pale yellow to deep reddish brown and is in flakes up to 0·6 mm. long making up approximately 5% of the rock. Plagioclase is in equidimensional grains, often partly saussuritised in the marginal parts but water-clear in the centre where it shows slight gradational reverse zoning to more albitic plagioclase at the centre of the crystal. Twinning although present in some grains is not common. The average composition is

andesine (Ab_{65} An_{35}). The most abundant accessory is black opaque iron ore (? magnetite) in irregular-shaped grains showing slight elongation parallel to the foliation of the rock. Apatite in small stout prisms is the only other accessory. The few large (5 mm.) porphyroblasts are of andesine (α' in cleavage fragments 1·550).

The rock has been completely recrystallised and all original structures have been obscured. There is no evidence of the presence of bands of different composition which might indicate a sedimentary origin and because of its uniformity in character throughout it is most probably a recrystallised basic igneous rock, such as a meta-basalt or meta-dolerite.

IIIB2 :—*Quartz-plagioclase-biotite-hornblende gneiss* (24497 from Point Malcolm). A dark grey to black schistose rock uniform in character throughout. In thin section the structure is coarse schistose, the average grain-size being 1 mm. and both the biotite and more abundant hornblende have a very platy habit and good orientation parallel to the foliation. The estimated proportions by volume of the constituents are blue-green hornblende (60%), greenish brown biotite 10%, plagioclase 20%, quartz 10% with accessory sphene. The plagioclase is water-clear andesine, mostly untwinned, with ($\pm$)2V near 90°. Specimen 7828 from Two People Bay, a medium-grained mesocratic gneiss, is a rock which is intermediate in character between the basic lenses of this group (IIIB2) and the acid gneisses of group (IC3a). It is a medium-grained granoblastic gneissic rock in which the estimated proportions of the minerals present are hornblende 35%, biotite 25%, plagioclase 25%, quartz 15% with accessory apatite and sphene.

C. *Containing hornblende and pyroxene.*

IIIC1a :—*Spinel-bearing plagioclase-hornblende-hypersthene granulite* (= basic charnockite) (24522 from the Eyre Highway at 10 miles east of Fraser Range homestead). A melanocratic coarse-grained granulose rock of gabbroidal appearance (named "gabbro" in the field) with no sign of banded structure in hand specimen.

In thin section the microstructure is coarse granulose with sub-blastophitic relations between the plagioclase and hypersthene. The approximate proportions of the constituents are hypersthene (65%), hornblende 15%, plagioclase (20%), and accessory spinel. The hypersthene is in large xenoblastic prisms and equidimensional grains to 4 mm. diameter and in aggregates of smaller clustered grains. The larger grains enclose plagioclase, hornblende, and spinel. It is a pleochroic iron-rich variety with ($\pm$)2V near 90°. The hornblende is intensely pleochroic with X yellow, Y deep reddish brown, Z deep reddish brown, $X < Y = Z$, $Z \wedge c = 15°$, optically negative with large 2V and, except for the large optic axial angle ($> 80°$) it looks like barkevikite. This is the only occurrence in the entire collection examined of this deep reddish brown hornblende. The plagioclase in this rock has the following properties :—is water-clear, well twinned, shows no zoning, optically positive, refractive index α' in cleavage fragments = 1·555 and therefore is an andesine-labradorite (Ab_{50} An_{50}).

Spinel is the most abundant accessory and is present in amounts up to 4 or 5%. It is a deep green isotropic pleonaste which occurs as irregular-shaped granules averaging 0·1 mm. diameter enclosed in the hypersthene and as small elongated prismatic euhedra enclosed in the plagioclase. There does not appear to be any regular pattern in the distribution of the spinel. The only other accessory present is an occasional small grain of magnetite.

IIIC1b :—*Plagioclase-diopside-hornblende granulite* (23312 from Rocky Gully). A medium grained granulose melanocratic rock with lighter green areas 2 mm. diameter containing diopside scattered uniformly throughout. Under the microscope the texture is granoblastic and the constituents are pale brownish-green hornblende, completely saussuritised plagioclase, pale green diopside, accessory black opaque iron ore, and, in one small area a little quartz, calcite, and epidote that have been secondarily introduced.

IIIC1c : —*Plagioclase-hornblende-pyroxene granulite* (20015 from Point Irby—see chemical analysis B in Table IV).

A massive dark grey, fine even-grained, granulose rock with no sign of banded structure, consisting of approximately equal proportions of plagioclase and ferromagnesian. In thin section the structure is granulose even-grained with average grain size 0·5 mm. and the constituents are plagioclase, clino-pyroxene, hypersthene, and hornblende with accessory magnetite and apatite. The hypersthene has poikiloblastic enclosures of plagioclase, is markedly pleochroic X pale red, Y yellow, Z pale green and optically negative, with γ approximately 1·73. The clinopyroxene is a pale greenish diopside with γ approximately 1·725 and the hornblende is a deep brownish green variety. The plagioclase is water-clear, comparatively free from twinning and has α' approximately 1·555 so is close to Ab_{50} An_{50}. The only accessories are magnetite and small stout prisms of apatite.

This rock petrographically closely resembles the plagioclase-hornblende-pyroxene granulites of Dangin and Bunker Bay (Prider, 1945, pp. 159–160) and this is borne out by the almost identical composition of the Point Irby rock (analysis B in Table IV) and that from Bunker Bay (analysis E in Table IV).

D. *Containing biotite, hornblende and pyroxene.*

The bulk of the basic granulite bands in the gneisses of the Strip fall into this group and with but few exceptions they are characterised by the presence of both ortho- and clino-pyroxene. They are similar to the plagio-clase-hornblende-pyroxene granulites described in the preceding section except for the presence of variable proportions of a reddish brown biotite. No examples have been noted of rocks containing hypersthene as the sole pyroxene.

IIID1b :—*Biotite-hornblende-pyroxene-plagioclase granulite* (W.A. Govt. Chem. Lab. No. 1623/48 from Cape Riche—*see* Geol. Surv. West. Aust. Ann. Rept. for 1948, p. 33).

A dark greyish, even-grained, granulose rock with a slight gneissic structure. The approximate proportions of the constituents seen in thin section are :—plagioclase 50 per cent., hornblende 40 percent., clinopyroxene 10 per cent., and accessory biotite and very rare apatite. In thin section there is a very poorly defined banding in the distribution of the clinopyroxene. The plagioclase is water-clear, fairly free from twinning, with α' in cleavage fragments = 1·548 and therefore andesine near $Ab_{60}An_{40}$. The hornblende is a brownish green variety with X yellow-green, Y brownish green, Z brownish green, and X $<$ Y = Z, in xenoblastic prisms averaging 1 mm. in length

which occasionally enclose the andesine. The clinopyroxene is a diopside in pale greenish xenoblastic prisms with Z $\wedge$ c to 42°, similar to that in the Point Irby rock described under IIID1c above. The only other constituent worthy of note is the biotite, which constitutes about 1 per cent. of the rock. It is a red-brown strongly pleochroic variety. An analysis of this specimen is given in column C of Table IV.

IIID1c :—*Biotite-hornblende-pyroxene-plagioclase gneiss* (16582 from Cape Riche—*see* chemical analysis D in Table IV). A mesocratic, medium-grained, gneissic rock, with brownish biotite plates to 1 mm. diameter well developed on the foliation planes. Under the microscope the texture is granoblastic gneissic with well developed parallel orientation of the biotite, hornblende, and pyroxene. The estimated approximate proportions of the constituents are :—plagioclase (50 per cent.), hornblende (15 per cent.), biotite (10 per cent.), hypersthene (10 per cent.), clinopyroxene (10 per cent.), with accessory magnetite and apatite. The plagioclase is water-clear andesine-labradorite close to $Ab_{50}An_{50}$ and the amphibole and pyroxenes are similar to those in the plagioclase-hornblende-pyroxene granulite described in IIIC1c above. The only essential difference between IIID1c and IIIC1c is in the presence in the former of abundant red-brown biotite.

IIID2c :—*Quartz-hornblende-pyroxene-plagioclase gneiss* (16583 from Cape Riche). A slightly gneissic, granulose, medium-grained greenish-grey rock with a lighter coloured coarser-textured granitic band. Under the microscope the rock has a granoblastic texture and consists, in order of abundance, of plagioclase, hornblende, clinopyroxene, hypersthene, quartz, orthoclase, biotite, magnetite and apatite. The plagioclase is a twinned water-clear andesine-labradorite often with antiperthitic structure. The hornblende, clinopyroxene, and biotite are similar to those minerals in specimen 16582 from the same locality (*see* under IIID1c above) but the hypersthene is almost completely replaced by pale greenish uralitic amphibole. In the lighter coloured coarser-textured band in this rock quartz is an important constituent and it is accompanied by a little orthoclase. Moreover in the vicinity of this orthoclase there is a development of myrmekite in the plagioclase and also of antiperthite. Potash has clearly been introduced to this part of the rock which is transitional in character between the basic remnants of the pre-granitic gneiss terrain (represented by IIID1c) and the granitization product (represented by the gneisses of group IE3a).

D. The intrusive granites.

The rocks considered in this section are intrusive into the gneisses described in section C above and they may be conveniently subdivided into :—

IVA. The earlier coarse porphyritic granites.

IVB. The later fine even-grained granites.

IVC. Porphyritic microgranites (quartz porphyries).

IVD. Pegmatites and associated aplites.

IVA. *Coarse porphyritic granites.*

Rocks of this group form large intrusions which are best exposed at Mts. Clarence and Melville at Albany, the Porongorups Range, Jarramongup and Esperance. This type of granite also occurs in narrow dykes, as for example at Point William near Albany where a dyke about 1 foot wide of porphyritic granite with flow-oriented tabular felspar phenocrysts of the order of 1 inch diameter is discordantly intrusive into the charnockitic gneisses. Chemical analyses (*see* Table V) have been made of porphyritic granites from Albany and from Esperance and petrographic descriptions of these rocks are given below. For the most part these porphyritic granites are characterised by the parallel orientation (? flow orientation) of the tabular felspar phenocrysts. There is some variation in the mineralogy of these rocks and they have been subdivided, on the basis of the ferromagnesians present into the sub-groups :—

1. With biotite only.
2. With biotite + hornblende.
3. With biotite + pyroxene ± hornblende.

TABLE V.

South Coast granites.

	A	B	C	D
SiO_2	66·90	71·40	73·69	69·65
Al_2O_3	14·76	14·73	13·61	15·37
Fe_2O_3	0·32	1·01	0·22	0·79
FeO	5·01	2·38	1·92	3·54
MnO	0·12	Tr.	0·04	0·17
MgO	0·93	0·14	0·32	0·26
CaO	2·46	1·92	1·06	1·83
Na_2O	2·42	2·92	3·32	2·37
K_2O	5·04	4·46	5·43	4·31
H_2O+	0·93	0·62	0·37	1·33
H_2O-	0·08	0·08	0·04	0·09
TiO_2	0·63	0·38	0·18	0·22
CO_2	*Nil*	*Nil*	*Nil*	*Nil*
P_2O_5	0·21	0·05	0·05	Tr.
	99·81	100·09	100·25	99·93
Norms.				
Q	23·88	31·62	29·64	32·46
or	29·47	26·69	32·25	25·58
ab	20·44	24·63	27·77	19·91
an	11·40	9·45	5·28	9·17
C	1·22	1·53	0·31	3·47
hy	10·22	3·20	3·70	6·41
il	1·22	0·76	0·46	0·46
mg	0·46	1·39	0·23	1·16
ap	0·34	....	....	....
C.I.P.W. Classification	I.4.2.3.	I.4.2.3.	I.4.2.3.	I.4.2.3.

A. Porphyritic granite (adamellite) (30974), Albany.

B. Porphyritic granite (adamellite) (24457), Esperance.

C. Fine even-grained granite (30975), Albany.

D. Porphyritic microgranite (23259), Point Hillier.

(All analyses by W. H. Herdsman.)

IVA1 :—*Porphyritic biotite adamellite* (24457 from Esperance—*see* analysis B in Table V).

A medium- to coarse-grained, slightly porphyritic, pink granitic rock with pink microperthitic alkali-felspar phenocrysts up to 2 cms. long showing simple twinning in hand specimen. White plagioclase which is present in the coarse granitic matrix is almost as abundant as the pink alkali felspar so that these porphyritic granites are best described as adamellites. There is a faint gneissic structure due to the sub-parallel orientation of the pink felspars. The only ferromagnesian appears to be small black biotite flakes. Under the microscope the texture is coarse allotriomorphic granular and the constituents are microperthitic microcline, plagioclase, quartz, and biotite with apatite, zircon, and magnetite as the accessories and very rare muscovite and calcite as secondary minerals.

Alkali-felspar, the most abundant mineral present is water-clear, except for slight tubidity along fractures and some cleavages, and has a microperthitic structure. It is generally free from the characteristic cross-hatched twinning of microcline but some crystals show a patchy and irregular cross-hatching and appear to be orthoclase inverting to microcline rather than primary microcline. Enclosures in the orthoclase include small rounded quartz and larger turbid plagioclase grains. The plagioclase in this rock is allotriomorphic, mostly turbid with fine sericitic material, and has extinction up to 7° in sections normal to the albite twin lamellae and refractive indices slightly higher than balsam indicating that it is an oligoclase near $Ab_{75}An_{25}$. In the oligoclase in contact with the alkali-felspar there is a notable development of myrmekite. Quartz is abundant in large allotriomorphs some of which show undulatory extinction due to strain. The biotite is a deep brown variety pleochroic from yellow to dark brown and shows considerable alteration along the cleavages to green weakly birefringent chlorite. The biotites tend to occur in clotted aggregates within which they are in more or less parallel alignment producing a poorly defined gneissic structure in the rock which is parallel to the flow orientation of the pink felspar phenocrysts.

The accessories are apatite, magnetite, and zircon and these tend to be concentrated in the vicinity of the biotite. The zircon is in stout, zoned euhedral prisms up to 0·3 mm. in length. There is a very small amount of muscovite and secondary calcite associated with some of the biotite.

A chemical analysis of this rock is set down in column B of Table V and the normative composition indicates that plagioclase is slightly more abundant than the alkali felspar so that these porphyritic granites are actually adamellites as suggested by the proportion of plagioclase and alkali felspar in hand-specimen.

IVA2 :—*Porphyritic biotite-hornblende adamellite* (30974 from Mt. Melville, Albany—*see* analysis A in Table V).

A grey coarse phaneric rock with porphyritic texture due to the presence of abundant euhedral tabular phenocrysts of alkali-felspar. The structure is slightly gneissic due to the flow alignment of the felspar phenocrysts which in this specimen measure up to 1 inch in length. In other specimens from the same quarry large tabular felspar phenocrysts 8 cm. diameter and 2 cm. thick occur. Most of the phenocrysts show simple twinning and contain enclosures of turbid plagioclase, biotite and quartz similar to the material

of the surrounding groundmass, strongly suggesting that the phenocrysts are really porphyroblasts. These enclosures are more abundant in the marginal parts of the phenocrysts. The microcline shows very irregular cross-hatched twinning similar to that in the Esperance granite (IVA1 above) and is orthoclase which has inverted to microcline. Moreover it is characterised by its fine microperthitic character.

The groundmass is coarse-grained, allotriomorphic-granular in texture, and consists of quartz, plagioclase, microcline, biotite, and hornblende with accessory magnetite, sphene, calcite and apatite. The microcline is water-clear, microperthitic and carries inclusions of quartz, biotite, and turbid plagioclase as do the larger phenocrysts. The plagioclase is mostly turbid because of saussuritization but this turbidity is of patchy occurrence and some parts of the plagioclase grains are water-clear. The plagioclase is an acid andesine ($Ab_{68}An_{32}$) with extinction 15° in sections normal to a and is being replaced to some extent by alkali-felspar which occurs as irregular-shaped grains within the andesine, in some cases growing along the cleavages.

The biotite is a brownish strongly pleochroic variety which is in part chloritised as in the Esperance rock. It occurs in clotted aggregates which are elongated parallel to the faint foliation of the rock. A little green-brown hornblende containing some rounded quartz inclusions is associated with some of these biotite clots but is comparatively rare in the slices examined. In the field this granite is characterised by the presence of occasional small black dots and lenticles up to several inches long of hornblendic material and the isolated hornblende grains present in the specimen under description are no doubt the xenocrystal equivalent of these hornblendic xenoliths. The main accessories—apatite, sphene with magnetite inclusions, and zircon—tend to be concentrated in the biotitic clots as does the rare secondary carbonate which occurs in irregular shaped grains.

An analysis of this rock is set down in column A of Table V, and it will be noted that it is an adamellite slightly more basic than the specimen from Esperance.

IVA3 :—*Porphyritic biotite-pyroxene adamellite* (31303 from Jarramongup).

A coarse-textured, pinkish grey, porphyritic rock with pinkish euhedral microcline phenocrysts up to 4 cm. long which make up 35 per cent. by volume of the rock, in a mesocratic coarse-grained groundmass of white plagioclase, pink microcline, quartz, pyroxene, and biotite. Under the microscope the microcline phenocrysts are similar to those in the Albany and Esperance rocks described above, *i.e.*, they are characterised by microperthitic structures, irregular cross-hatched twinning indicating derivation from orthoclase, and inclusions of the minerals which form the groundmass indicating that they are porphyroblasts rather than phenocrysts. The matrix has a coarse allotriomorphic-granular texture and consists of partly sericitised plagioclase ($Ab_{75}An_{25}$), microcline, quartz, pyroxene, biotite, magnetite, and accessory apatite and zircon, the apatite being concentrated in the vicinity of the biotite-pyroxene aggregates.

The biotite is a strongly pleochroic reddish brown variety which occasionally has later growths of quartz along the cleavage. It occurs in clotted aggregates with the pyroxene which is represented by two varieties :—(i) A pale greenish unaltered optically positive clinopyroxene with $\beta = 1 \cdot 705$ and therefore approximately $Di_{54}Hd_{46}$, and (ii) a pleochroic hypersthene which is almost completely replaced by pale greenish fibrous bastite and granular magnetite. A green-brown hornblende is present but is very rare in amount. A Rosiwal analysis of the granitic matrix which constitutes 65% by volume of this rock by Mr. Ian Threadgold yielded the following :—

	% by volume
Oligoclase	60·7
Clinopyroxene	11·0
Orthopyroxene	2·1
Biotite	8·5
Quartz	8·5
Microcline	6·7
Iron Ores	2·0
Apatite	0·5

Hornblende is very rare in this rock but in another representative of this group (20048 from Torbay Head) hornblende is abundant.

As in the porphyritic adamellites of Albany and Esperance it is evident that the " phenocrysts " are actually porphyroblasts which enclose the various minerals and mineral aggregates of the groundmass. Moreover the tendency of the biotite and pyroxenes to occur in clotted aggregates within which there is a concentration of apatite is highly suggestive of a palingenetic origin for this rock. In the biotite, clinopyroxene, hypersthene, and sericitised plagioclase we find a link with the charnockitic gneisses and their associated biotite-pyroxene-plagioclase granulites which have been described in the section on gneisses above, and there can be little doubt that the Jarramongup granite is of palingenetic origin being derived from the older charnockitic gneisses. At the same time flow orientation of the microcline porphyroblasts indicates that this rock is not simply a granitization (*i.e.*, altered *in situ*) product but has formed from the felspathization of the older gneisses which have been mobilised and intruded into a higher level.

IVB. *Fine to medium, even-grained granites.*

The granites of this group are intrusive into the gneisses (I–III above) and the coarse porphyritic granites (IVA above), generally occurring as flat-lying dykes of the order of ten feet in thickness. Good exposures of these narrow flat-lying dykes in the gneisses can be seen at Cave Point, Albany, and fine-grained granite intrusions into the coarse porphyritic granites are well exposed in the Burt Street quarry near the High School, Albany, and in Hartman's Quarry on Mt. Melville at Albany. At the latter locality the fine-grained granite, which occurs in a flat-lying dyke, is discordant to the platy flow orientation of the coarse porphyritic adamellite. This specimen has been taken as typical and a chemical analysis of it is set down in Table V and a brief petrographic description is :—

IVB1 :—*Fine-grained biotite adamellite* (30975 from Mt. Melville, Albany). A light-grey, fine, even-grained, granitic-textured rock with biotite as the ferromagnesian. In the few inches immediately adjacent to the wall of the dyke there is a faint flow orientation of the biotite flakes.

Under the microscope the texture is even-grained allotriomorphic granular with poikilitic relations between microcline and earlier quartz and plagioclase. The constituents, in order of abundance, are microcline, quartz, plagioclase, and biotite, with accessory epidote, zircon, and apatite. The microcline is water-clear, slightly microperthitic, shows crosshatched twinning and poikilitically encloses rounded quartz grains, turbid sericitised plagioclase grains which have a clear marginal zone, and biotite. The plagioclase is anhedral and turbid from sericitic and fine granular zoisitic alteration products. The marginal parts of the plagioclase grains are, however, water-clear, particularly when they are included in the microcline. The plagioclase shows lamellar twinning, has refractive indices slightly greater than balsam and extinction angle up to 8° and is therefore oligoclase close to $Ab_{75}An_{25}$. The biotite is in irregular shaped greenish brown flakes with associated accessory epidote and apatite and here again there is a tendency for the biotites to occur in aggregates rather than single crystals distributed uniformly throughout the rock.

The chemical analysis of this rock (C in Table V) indicates that the significant difference from the porphyritic granites lies in the Na/Ca ratio, the fine-grained granites being much richer in soda than the earlier porphyritic granites. All of the granites both porphyritic and equigranular are best described as adamellites.

IVB2 :—*Fine-grained biotite-hornblende adamellite* (24467 from Mt. Le Grand). A fine even-grained, dark greyish, phaneric rock which near the edge of the intrusion has a faint flow banding. Under the microscope the rock is allotriomorphic granular in texture and consists of alkali-felspar, plagioclase, quartz, biotite, hornblende, and accessory apatite, magnetite and sphene, and a little secondary carbonate. The alkali-felspar is slightly microperthitic and for the most part devoid of the cross-hatched twinning although patchy cross-hatching is occasionally present. The biotite is a brownish variety and far exceeds in amount the greenish hornblende which occurs in irregular-shaped embayed prisms. This rock is similar to the fine-grained biotite adamellite with the addition of small amounts of hornblende.

IVC. *Porphyritic microgranites.*

Porphyry dykes are of rare occurrence in the Strip, having been noted only at Pt. Hillier and on the Ravensthorpe-Hamersley Inlet track at 7½ miles S.S.W. of Ravensthorpe. Specimen 23259 from a N.W. striking dyke 15 feet wide intrusive into gneiss near Point Hillier at ¾-mile south of the mouth of Parry Inlet has been chosen as typical and a chemical analysis of this rock is set down in column D of Table V.

This rock has a porphyritic texture with phenocrysts of bluish quartz up to 1 mm. diameter in a dark grey, dense aphanitic groundmass. The specimen is traversed by thin quartz veinlets but the material submitted for chemical analysis was free of such veins. Under the microscope the rock has a porphyritic texture with phenocrysts of subhedral quartz and almost completely sericitised untwinned felspar which is too altered for determination, in a microgranitic groundmass of quartz, sericitised felspar and pale brownish biotite. The thin quartz veinlets are characterised by the presence of fluorite which is associated with an opaque bluish black ore mineral (? magnetite) and there is a noticeable recrystallisation of the sericite of the micrograntic groundmass along the walls of these veinlets.

A chemical analysis of this rock is given in column D of Table V from which it will be seen that this rock, chemically, is very similar to the porphyritic granite from Esperance. The high normative corundum is due to the sericitisation of the felspar.

IVD. *Pegmatites and associated aplites.*

Very few outcrops of the gneisses or granites of the South Coast area are devoid of pegmatite-aplite veins or segregations. These consist essentially of quartz, microperthitic microcline, and oligoclase-albite with biotite and/or hornblende. Mr. Allan F. Wilson has discovered radioactive minerals in a number of these pegmatites at Doubtful Island Bay and in the Porongorups and he is at the present time carrying out further work on these minerals the results of which will appear in a later paper.

E. The Stirling Range metasediments.

The sediments of the Stirling Range beds are all of very low grade metamorphism and with but few exceptions (in highly sheared zones) are characterised by the presence of the original clastic textures and structures. They consist predominantly of thin-bedded purplish orthoquartzites and fine-grained phyllites with wide-spaced fracture cleavage in the quartzites and close-spaced fracture cleavage in the phyllites. Many of the quartzites show well-developed current ripple-marks and a notable feature is the variation in the direction of the ripple marks in different layers indicating quick variation in current directions (? tidal flat conditions). In the vicinity of the Tenterden Slate Quarry on Location 2772 there is a coarser facies, not noted elsewhere in the Range, represented by a fine conglomeratic orthoquartzite. In the vicinity of zones of intense overfolding the phyllites have been contorted and recrystallised yielding fine-grained contorted quartz-green muscovite schists which cannot be distinguished lithologically from the green mica schists of the Pt. Ann-Pt. Charles section of the coast to the south-east. There is a complete absence of calcareous sediments in this succession which is a shallow water (tidal flat) facies. Typical specimens are: –

(i) *Fine-grained conglomeratic ortho-quartzite* (25324 from vicinity of Tenterden Slate Quarry on Loc. 2772). A white rock which on exposed weathered surfaces looks at first like white vein quartz. On fresh fractured surfaces the rock has a coarse clastic texture being made up of approximately 40% of well-rounded quartz grains averaging 3 mm. diameter tightly cemented by a finer arenaceous matrix of rounded quartz grains. Amongst the larger fragments are a few up to 6 mm. diameter of opaque pure white chert.

Under the microscope the arenaceous matrix has a clastic structure. It consists of perfectly rounded quartz grains averaging 0·7 mm. diameter with irregular outgrowths of quartz in optical continuity which completely fill the interstices so that, neglecting the zones of dusty inclusions marking the margins of the original rounded grains, the texture becomes almost granoblastic. Most of the detrital quartz grains show slight undulose extinction and are characterised by well-developed very close-spaced Boehm lamellae. The larger rounded quartz fragments consist generally of coarse allotriomorphic granular aggregates of anhedral quartz grains which may have been derived from vein quartz or quartzite. Other than the few chert fragments quartz is the only mineral present in this rock.

(ii) *Sericitic quartzite* (8755 from Phillipps' Spur on south flank of Toolbrunup). A purplish grey dense ripple-marked quartzite consisting of light greyish beds 3 cm. thick interbedded with darker purplish grey finer grained beds to 1 cm. thick. The coarser textured beds in thin section have a clastic texture consisting of fairly well graded quartz sand grains averaging 0·3 mm. diameter in a chalcedonic and sericitic matrix. The quartz grains are occasionally well rounded but the original rounding has been largely obscured by optically continuous authigenic outgrowths so that for the most part the detrital grains appear to be angular. Most of the quartz grains show strain in the form of undulose extinction. The arenaceous detrital material is absolutely free from felspar. Occasional heavy detrital grains of tourmaline are present but are more abundant in the finer-textured layers. In these fine-grained bands the quartz sand grains average 0·1 mm. diameter and constitute approximately 70% of the rock. For the most part these grains are sub-angular and show very slight wear only but there is a marked dimensional orientation of these grains which have been deposited with their longer axes parallel to the bedding. The matrix consists of admixed chalcedony, pale green fibrous chlorite, and brightly polarising sericite which is of metamorphic development and occurs in tiny parallel oriented flakes. Heavy detritals including irregular shaped opaque iron ores, greenish brown tourmaline, and rounded purple zircons are comparatively abundant in these more sericitic layers and moreover there is a marked tendency for them to be concentrated in thin heavy mineral bands within these sericitic layers. The zircon is a purple variety in grains averaging 0·05 mm. diameter and the tourmaline, in grains 0·08 mm. diameter, is a characteristic greenish brown strongly pleochroic variety with ω = deep bluish green to brownish green and ϵ = pale clove-brown to colourless. Some of the tourmaline grains have a zonal coloration being brownish green in the centre and bluish green on the margins. The varietal features of the zircon and unusual tourmaline in the Stirling Range quartzites are similar to those of the quartzites of the Mt. Barren metasediments which have been described in Section VA above.

(iii) *Phyllite* (16592 from Ellen Peak). A purplish grey, fine-grained, silky lustred, fissile rock with minute glistening mica flakes on the rock cleavage. Under the microscope the texture is extremely fine-grained and there is a complete absence of silt and sand grade material. The rock consists of a fine aggregate of clayey material, very fine sericite and chlorite, dusted with reddish brown hematite and black opaque iron ore. This rock has not suffered any appreciable recrystallisation.

(iv) *Contorted quartz-muscovite schist* (25337) from 4¼ miles S.E. of crest of Yungermere). An intensely contorted, light greenish grey, silky lustred phyllitic schist. In the field this contorted schist has white coarse-grained quartz bands (? vein quartz) up to 1 inch wide which follow the contortions of the intensely folded schist. Under the microscope this rock is indistinguishable from the quartz-green muscovite schists of Point Charles (described in Section *VA* of this paper), the constituents being pale green highly birefringent muscovite, pale green chlorite, quartz, and bluish black opaque (?) ilmenite in elongated platy or prismatic grains. The chlorite is present in two forms—

(i) as plates associated with the green muscovite and arranged parallel to the contorted foliation and (ii) in folded bands up to 0·25 mm. wide associated with tiny quartz grains, within which bands the chlorite flakes are oriented normal to the foliation but parallel to the well developed strain-slip cleavage. The most significant of the heavy minerals is the greenish brown tourmaline which, as has been previously noted, is a constant constituent of the Stirling Range sediments and also of the schists of the Barrens belt as exposed at Point Charles.

The contorted quartz-muscovite schists carry numerous thin quartz veinlets up to 2 inches thick which follow the contortions of the foliation. These veinlets (25349) have a central cavernous zone carrying siderite and more rarely, in the centre of the siderite zone, micaceous hematite in flaky crystals up to 1 cm. diameter.

Within these highly disturbed zones, considered to be in the vicinity of overthrusts, the pelitic sediments are represented by the contorted schists described above and the arenaceous phase is represented by fine-grained, pale greenish grey, fissile rocks with a silky lustre on the foliation planes (25338). Under the microscope the rock retains its clastic structure, consisting of sub-angular quartz grains in a matrix of fine granular quartz and flaky pale greenish muscovite similar to that in the associated contorted schists. There do not appear to be any marked strain effects in the clastic grains, most of the movement having been taken up by the finer-grained matrix. In this rock greenish brown tourmaline is again the commonest heavy detrital mineral.

F. Basic igneous intrusives.

This group includes the basic dykes intrusive into the gneisses, granites and metasedimentary rocks of the Strip. They are intrusive into the Stirling Range beds which are considered to be of Proterozoic age and they represent the latest phase of igneous activity of which there is evidence. The main rock types are quartz dolerite and uralitized quartz dolerite and it is considered that these basic dykes are undoubtedly co-magmatic with the late-Nullagine basic dykes of the South-West of W.A. (Prider, 1948, pp. 67–71).

Within this group there are variations in the rocks, both in textural features (due mainly to different rates of cooling) and in mineralogy (due in part to differentiation and in part to metamorphic or deuteric processes). They may be subdivided as follows :—

V. Basic Dyke Rocks :—

- A. Quartz dolerites :—
  - 1. Uniform-textured, fine- to medium-grained.
  - 2. Porphyritic.
- B. Uralitized quartz dolerites.
- C. Chloritised quartz dolerites (subdivided as in A.).
- D. Olivine dolerites :—
  - 1. Even-medium-grained.
  - 2. Microporphyritic.
- E. Quartz diorites.

TABLE VI.

Basic dyke rocks from the South Coast strip.

	A.	B.	C.	D.	E.	F.	G.
SiO_2	44·34	48·36	49·04	49·42	49·43	59·64	49·13
Al_2O_3	16·12	17·16	15·02	15·37	14·28	13·83	13·13
Fe_2O_3	2·76	0·79	1·82	1·84	2·08	1·67	3·65
FeO	11·52	10·88	11·61	12·23	13·10	9·58	8·95
MnO	0·27	0·18	0·24	0·26	0·24	0·23	0·15
MgO	5·14	2·69	5·73	5·32	5·78	2·08	7·64
CaO	8·38	8·64	10·42	10·13	9·06	5·66	11·84
Na_2O	2·76	2·33	2·06	1·94	1·93	3·15	1·72
K_2O	1·28	2·44	0·49	0·89	0·86	0·92	0·16
H_2+	2·89	2·20	2·28	0·40	0·16	1·26	1·72
H_2O-	0·12	0·12	0·12	*Nil*	0·19	0·22	0·04
TiO_2	2·86	2·82	0·96	1·76	2·36	1·18	1·27
P_2O_5	0·92	1·26	0·09	0·28	0·27	0·32	0·14
CO_2	*Nil*	*Nil*	*Nil*	*Nil*	Tr.	*Nil*	....
FeS_2	0·47	....	..	....	....	.. .	0·45
Total	99·83	99·87	99·88	99·84	99·74	99·74	99·99
—O=S	0·12					—O=S	0·11
	99·71						99·88

Norms :

	A.	B.	C.	D.	E.	F.	G.
Q	....	1·08	0·78	1·26	2·28	17·88	3·48
or	7·78	14·46	2·78	5·56	5·56	5·56	1·11
ab	23·58	19·39	17·29	16·24	16·24	26·72	14·15
an	27·52	29·19	30·30	30·58	27·52	20·57	27·52
di	7·15	4·50	17·16	14·84	13·00	4·77	24·88
hy	4·94	19·50	24·33	24·36	26·65	17·27	18·33
ol	13·91	....	....	....	....	....	....
il	5·47	5·32	1·82	3·34	4·56	2·28	2·43
mg	4·18	1·16	2·55	2·55	3·02	2·55	5·34
ap	2·02	3·02	0·34	0·67	0·67	0·67	0·34
py	0·47	....	....	....	....	....	0·45
C.I.P.W.	III.5·4·3	II.5·4·2	III.5·4·3	III.5·4·3	III.5·4·3	II.4·3·4	III.5·4·3

A. Chloritised dolerite (VC1) (Specimen 23275 from Point Hillier, W.A.). *Anal.* W. H. Herdsman.

B. Porphyritic dolerite (VA2) (Specimen 23261 from Point Hillier, W.A.). *Anal.* W. H. Herdsman.

C. Uralitised quartz dolerite (VB1) (Specimen 8762 from the east face of Mt. Hassell, Stirling Range, W.A.). *Anal.* W. H. Herdsman.

D. Quartz dolerite (VA1) (Specimen 20051 from West Cape Howe, W.A.). *Anal.* W. H. Herdsman.

E. Basaltic olivine dolerite (VD2) (Specimen 20018 from chilled margin of dyke, Point Irby, W.A.). *Anal.* W. H. Herdsman.

F. Quartz diorite (VE) (Specimen 25327 from near Tenterden Slate Quarry, Stirling Range, W.A.). *Anal.* W. H. Herdsman.

G. Quartz dolerite from Toodyay, W.A. for comparison with the South Coast dolerites (quoted from Prider, 1944, p. 127).

Petrographic descriptions of typical specimens are as follows :—

VA1 :—*Quartz dolerite* (20051) from West Cape Howe, *see* analysis D in Table VI).

An even-medium-grained, dark grey melanocratic rock with average grain size 1 mm. Under the microscope the texture is uniform, hypidiomorphic-granular with ophitic relations between plagioclase and pyroxene. The constituents in order of abundance are essential plagioclase and pyroxene and accessory ilmenite, quartz, orthoclase, hornblende, biotite, and apatite. The plagioclase is in water-clear lath-shaped crystals up to 2 mm. long, with well developed lamellar twinning and slight gradational normal zoning. It is optically positive, has N greater than balsam, and extinction up to 28° in sections normal to a and is therefore close to $Ab_{50}An_{50}$ in composition. The pyroxene is mostly free from alteration except in the immediate vicinity of end-stage quartz where it is either rimmed by brownish green hornblende or slightly uralitised and dusted with black iron ore grains. The pyroxene appears to be of uniform character throughout the rock and throughout the individual grains. It has a slight purplish tinge due to titania and is very slightly pleochroic, has β approximately $1 \cdot 715$ and $(+)$ 2V approximately 40° and so is a member of the clino-enstatite-hedenbergite series with approximately 70% of the hedenbergite molecule.

Ilmenite is the most abundant of the accessories. It occurs in fresh skeletal-shaped grains to 3 mm. diameter which enclose both plagioclase and pyroxene in an ophitic fashion. There is no trace of leucoxene associated with this ilmenite but there is occasionally a little reddish brown biotite moulded on the iron ore, particularly in the vicinity of the end-stage quartz. The end-stage quartz is associated with water-clear to slightly cloudy orthoclase in angular areas interstitial to the plagioclase laths. Small prismatic apatite euhedra are often associated with this quartz-orthoclase mesostasis and in some places biotite and brown-green hornblende also. Where the pyroxene is adjacent to this mesostasis it is slightly uralitised.

The chemical analysis of this rock set down in column D of Table VI indicates its tholeiitic character.

VA2 :—*Porphyritic quartz dolerite* (23261 from Pt. Hillier (*see* analysis B in Table VI)). A dense melanocratic porphyritic rock with elongated prismatic felspar phenocrysts up to 7 mm. in length in an aphanitic dark greenish matrix. The felspar phenocrysts, which have a flow orientation, although water-clear in places, are considerably saussuritised and have chloritic growths along cleavages and cracks. They have refractive indices greater than balsam and the extinction up to 25° indicates they are at least as basic as $Ab_{55}An_{45}$. The groundmass is a microcrystalline aggregate of saussuritised plagioclase and pyroxene. Within the groundmass, over patches up to 1 sq. mm. in area, the dispersed pyroxene grains have a common orientation. The pyroxene is a non-pleochroic titania-rich augite with a strong reddish-violet colouration which differs markedly from that in the normal quartz dolerites and their uralitised derivatives. Throughout the very turbid groundmass there are stout euhedral prisms of apatite but the most noticeable feature of the groundmass is the occurrence of abundant black opaque slightly leucoxenised ilmenite prisms up to $0 \cdot 3$ mm. in length. Within areas up to 2 mm. diameter these ilmenite prisms are in parallel alignment or in two intersecting sets but the orientation differs in adjacent areas. These peculiar structures appear to be an initial step in the build-up of the larger skeletal ilmenites seen in the coarser textured quartz dolerites. There are several angular areas in the slice up

to $2\frac{1}{2}$ mm. diameter consisting of a fine-grained allotriomorphic granular aggregate of quartz with a little carbonate, abundant stout euhedral apatite rods and some pyrrhotite.

This rock, in its porphyritic texture, the absence of ophitic texture in the groundmass, the deep-coloured titaniferous pyroxene, and the peculiar occurrence of the ilmenite differs markedly from the normal dolerites. An analysis of this rock is given in column B of Table VI and its most marked features are the higher TiO_2, P_2O_5, K_2O and Al_2O_3 proportions than in the normal quartz dolerites. The reason for these differences is not apparent—it may be that these basic dyke rocks crystallised from a melt in which there has been, by some process of gaseous transfer, an enrichment in the alkalies, TiO_2 and P_2O_5.

Porphyritic dolerites of this group occur only at Point Hillier (where a chloritised variety of the same rock occurs—*see* under VC2 below).

VB1 :—*Uralitised quartz dolerite* (8762 from Mt. Hassell, Stirling Range—*see* analysis C in Table VI). An even medium-grained, greenish melanocratic rock consisting essentially of dark green ferromagnesian and greenish white felspar. The rock has an ophitic texture and consists of saussuritised plagioclase, partially uralitised pyroxene (much of which however is perfectly unaltered), quartz, slightly leucoxenised ilmenite, apatite, a little brown-green hornblende and rare reddish brown biotite. With the exception of the saussuritised nature of the plagioclase and the uralitisation of the pyroxene this rock is similar to the normal quartz dolerite (VA1)—a similarity which is emphasised by the chemical analyses (*see* analyses C and D in Table VI). The uralitised quartz dolerites are much more abundant than the perfectly unaltered variety and examples of all stages of uralitization up to the complete obliteration of the original pyroxene have been noted.

VC1 :—*Chloritised dolerite* (23275 from Pt. Hillier—*see* analysis A, Table VI). A fine even-grained, massive, dark green to black rock characterised by the presence of numerous evenly spaced soft black bodies up to 3 mm. diameter (averaging 1 mm. diameter) which constitute approximately 20 per cent. of the rock. Some of these are almost spherical. On weathered surfaces these soft masses have weathered out giving the rock a pseudo-vesicular character. Accessory pyrite is scattered sparsely throughout the rock.

In thin section the texture is slightly porphyritic with chloritic aggregates (the soft black bodies seen in hand specimen) replacing (?) pyroxene phenocrysts which occur in a much uralitised and chloritised ophitic textured groundmass. The chloritised phenocrysts which are penetrated ophitically by plagioclase laths (indicating that the parent mineral was most probably pyroxene rather than olivine) consist of a decussate aggregate of small chlorite flakes averaging $0 \cdot 03$ mm. diameter. This chlorite is very weakly birefringent, yellow green in colour, pleochroic from X yellow-green to Z clear green, and has positive optical elongation (*i.e.*, negative optical character) and $\beta = 1 \cdot 625$ and therefore is an aluminous aphrosiderite. This type of chlorite is not confined to the phenocrysts but also replaces pyroxene in the groundmass.

The groundmass of this rock has a well developed ophitic texture and consists of plagioclase, completely uralitised and chloritised pyroxene, a little euhedral epidote, and comparatively abundant leucoxenised ilmenite. There is no quartz present in this rock.

The plagioclase is dusted with tiny chloritic and sericitic flakes but is free from turbid saussurite. It shows lamellar twinning, has refractive index less than Canada balsam, 2V near 90° and extinction 4°, and is therefore an albite-oligoclase approximately $Ab_{85}An_{15}$. The original pyroxene has been completely replaced by pale greenish uralite, greenish brown biotite and yellow-green chlorite. The epidote is in prismatic euhedra generally included in the chloritic aggregates. Ilmenite, extensively altered to leucoxene, is the most abundant accessory and is dispersed evenly throughout the rock.

The chemical analysis of this rock (analysis A in Table VI) indicates that it is closely related to the porphyritic dolerite of group VA2 described above, the high TiO_2 content being its outstanding feature.

VC2 : *Chloritised porphyritic dolerite* (23273 from Pt. Hillier). This rock is similar texturally to 23261 of group VA2 from the same locality. It is however more chloritic and lighter in colour in hand specimen. Moreover it carries chloritic patches as does 23275 of group VC1 described above. In spite of the extensive chloritisation there is much residual titaniferous augite present. The ilmenite is in the characteristic structures noted above under VA2. This rock is undoubtedly the chloritised product of VA2.

VD1 :—*Even-grained olivine dolerite* (32657 from Pasley Island, Recherche Archipelago). A fine even-grained phaneric melanocratic rock which has an ophitic to intergranular texture and is composed, in order of abundance, of plagioclase ($Ab_{45}An_{55}$), titaniferous augite, and olivine with accessory opaque iron ore, biotite, quartz, and apatite. The plagioclase is in water-clear laths averaging 1 mm. in length. The titaniferous pyroxene is the same violet-coloured variety as in the porphyritic dolerite (VA2) from Pt. Hillier and is present in approximately the same amount as olivine. The olivine which is in subhedral and euhedral crystals averaging 0·3 mm. in length is largely colourless but in places stained with reddish iron oxide, and has (–)2V close to 90° and is therefore a forsterite close to $Fo_{90}Fa_{10}$. It is idiomorphic towards both the augite and plagioclase. Black opaque iron ore is the most abundant accessory and it is generally surrounded by reddish brown biotite. In spite of the abundance of olivine (approximately 15%) and the uniform grain size (averaging 1 mm.) of this rock there is a little quartz present in angular shaped grains occupying the interstices between plagioclase prisms—such quartz is invariably mantled with biotitic material. As in the normal quartz dolerites it appears to have been the last mineral to crystallise and since it encloses the characteristic apatite prisms it does not appear to be secondary or xenocrystal although there is a xenolith of quartz-turbid felspar rock present. The primary quartz of this olivine dolerite is present only in small amount as compared with the abundance of olivine and there can be little doubt that this rock is strongly undersaturated and therefore not a normal member of the quartz dolerite suite. The scarcity of olivine dolerites in W.A. has been previously noted (Prider, 1948, p. 69). The specimen from Pasley Island described above is the only representative of this group in the collection examined.

VD2 :—*Microporphyritic olivine dolerite* (20018 from Pt. Irby (*see* analysis E in Table VI)). A melanocratic aphanitic rock with microphenocrysts of prismatic plagioclase. The microporphyritic texture is more evident under the microscope with microphenocrysts of plagioclase to 0·6 mm. long and rare olivine set in an ophitic plagioclase-pyroxene-iron ore groundmass in which the average grain size is 0·15 mm. There is a marked flow alignment of the plagioclase laths. The plagioclase microphenocrysts are slightly zoned and average $Ab_{45}An_{55}$ in composition. The olivine is colourless and the larger grains are perfectly fresh although smaller grains in the groundmass are replaced by serpentine. It has (+) 2V close to 90° and so is a forsterite-rich variety. The pyroxene is confined to the groundmass and is augite with pale violet colouration as in the normal quartz dolerites. The iron ore, evenly dispersed throughout the groundmass, occurs in small feathery cross structures. Quartz is absent.

An analysis of this specimen appears in column E of Table VI from which, in spite of its olivine content, it will be seen to be of tholeiitic character with 2·28% normative quartz. This specimen was collected from the chilled edge of a dyke which, in the central part is a phaneric, even-medium grained quartz dolerite free from olivine. The development of olivine in the chilled margins is due to the inhibition, owing to quick chilling, of the olivine-pyroxene reaction—in the slower cooling centre of the dyke this reaction has been able to proceed with the complete obliteration of the early-formed olivine. The presence of olivine in the chilled margins of other quartz dolerites has been noted at Pt. Hood and in the Fitzgerald River, the only other places from which specimens of chilled borders of dykes are available. These micro-porphyritic olivine dolerites are simulated by thin black veinlets, up to several inches wide, which occur in the gneisses of Willyun Creek (24128) but thin section examination of these rocks indicates that they are pseudo-tachylites and the " microphenocrysts " are micro-xenoclasts.

VE. :—*Quartz diorite* (25327 from vicinity of Tenterden Slate Quarry—see analysis F in Table VI). In hand specimen this rock is medium-grained, mottled white and greenish black, with a glomeroporphyritic appearance due to the tendency of the femics to occur in aggregates averaging 4 mm. diameter dispersed evenly throughout the specimen. This mottled appearance serves to distinguish these rocks from the uniformly melanocratic quartz dolerites which may be as coarse or even coarser textured. Microscopic examination shows that the texture is allotriomorphic to hypidiomorphic granular rather than ophitic as in the quartz dolerites, and that the minerals present, in order of abundance, are plagioclase, quartz, hornblende, biotite, pyroxene, accessory apatite and iron ore and secondary epidote and carbonate.

The plagioclase, in subhedral prisms averaging 1 mm. in length, is completely saussuritised except for a narrow rim of water-clear albite which has refractive index less than balsam. The saussurite completely masks the optical properties of the plagioclase and in places is recrystallised to an aggregate of epidote grains. The femic clots consist generally of an aggregate of biotite and hornblende but in the centre of a few of these basic clots there is rare remnant pyroxene. The pyroxene passes out to pale greenish uralitic amphibole which in turn grades into brown-green hornblende and thence into blue-green hornblende and biotite at the margins of the clots where they are in juxtaposition to the quartz-albite aggregate forming the remainder of the rock. Where isolated primary hornblendes occur in the quartz-felspar

groundmass they are brownish green in the centre grading out to blue-green hornblende on the margins. Isolated biotites also show this type of colour zoning being reddish brown in the centre and bright green on the margins and occasionally grading out to bright green chlorite. The primary hornblende poikilitically encloses opaque iron ore, stout prismatic apatite euhedra, and quartz. Apatite is an abundant accessory and appears to be concentrated in the femic clots.

Quartz is very abundant (estimated visually at approximately 20% by volume) in anhedra averaging 0·2 mm. diameter associated with the end-stage water-clear albite. Occasionally, coarse-grained epidote, different from that resulting from the alteration of the plagioclase, is associated with the quartz. More rarely there is a little carbonate in irregular-shaped anhedra present with this end-stage quartz.

A chemical analysis of this rock is set down under F in Table VI and the most noticeable feature is the high silica content yielding 18% of normative quartz. In view of the high quartz content, the highly saussuritised nature of the plagioclase, and the complete absence of K-felspar it is difficult to assign a name to this rock but it could best be described as a quartz-rich diorite. It occurs in a dyke approximately 1 chain wide which in the border zone several yards wide is a fine even-grained, slightly uralitised, ophitic quartz dolerite containing a considerable amount of primary brown-green hornblende (25328). This doleritic margin serves to illustrate the magmatic relation of this " quartz diorite " to the quartz dolerite suite. It appears to be a sodic and siliceous end-phase differentiate of the quartz dolerite magma.

VI. PETROGENESIS.

There are five main problems which arise from this geological reconnaissance of the South Coast Strip. They are :—

1. The relationship between the metasedimentary rocks of the Mt. Ragged area, the Gairdner R.-Phillips R. belt and the Stirling Range.

2. The origin of the gneisses and associated basic lenses.

3. The genesis of the granites.

4. The origin and relationships of the greenstones (including the quartz dolerite suite).

5. The disparity between the prevalent E.N.E. trend of the Pre-Cambrian rocks of the Strip and the N.W. and N.N.E. trends of the Ravensthorpe and Mt. Ragged belts.

These problems may be discussed summarily as follows :—

1. *The relationship of the metasedimentary rocks.*

The low grade Stirling Range metasediments are considered on the basis of the field evidence to be post-granite and pre-quartz dolerite in age and therefore to be the representatives in the South Coast area of the Nullagine (Proterozoic) System. The Mt. Ragged belt on the other hand is composed

of sillimanite zone metasediments and is probably intruded by pegmatites and is therefore considered to belong to the Archaean. The metasediments of the Gairdner R.-Phillips R. belt are, on the whole, more metamorphosed than the Stirling Range beds but are much lower in grade than the metasediments of the Mt. Ragged belt. They are intruded by greenstone sills which have been involved in the metamorphism but there is no positive evidence of their age relations to the granitic rocks and the problem arises as to where they come in the sequence.

The petrographic investigations indicate that these rocks are more closely related to the Stirling Range beds than to the Mt. Ragged metasediments since :—

(a) The Stirling Ra. beds although they generally retain the original clastic structures are, in the vicinity of the overthrusts, represented by contorted quartz-chlorite-green muscovite schists which are indistinguishable petrographically from those of the Pt. Ann-Pt. Charles section of the coast in the vicinity of the Mt. Barrens. Moreover in places the Mt. Barren metasediments (*e.g.*, 17476 from 3 miles west of the mouth of the Hamersley River) are indistinguishable from the very low grade phyllitic quartzites which constitute the bulk of the Stirling Range mass.

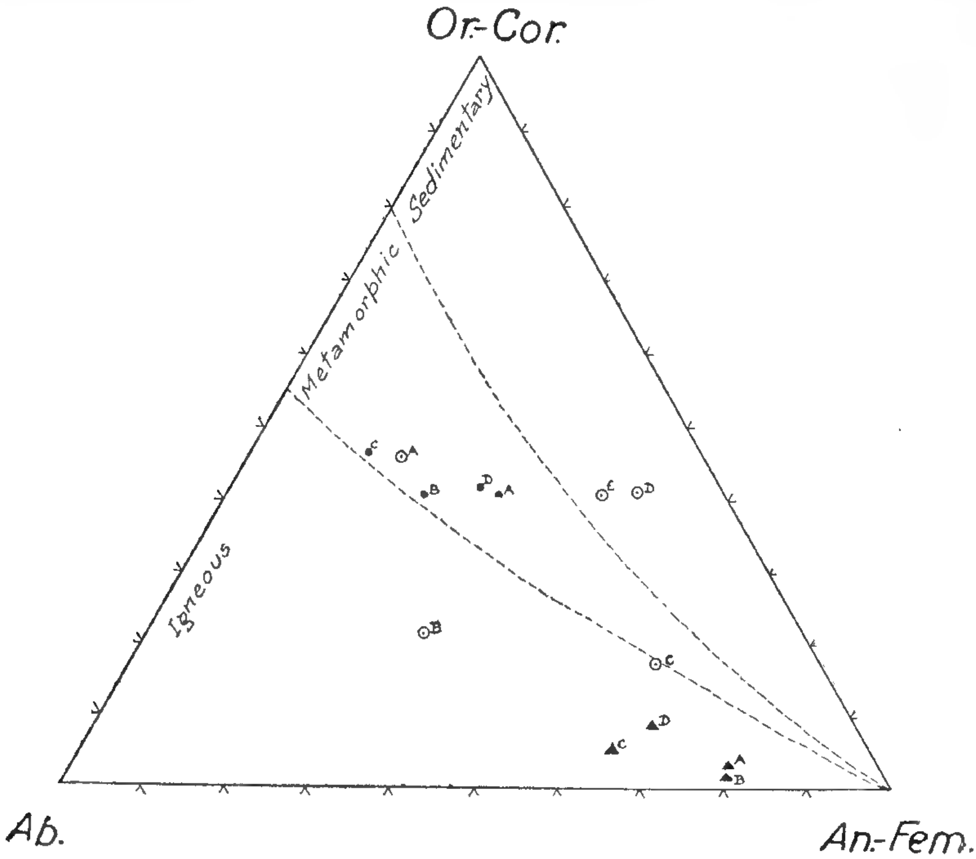
(b) There is a close similarity in the heavy detrital minerals of the Stirling Range beds and those of the Mt. Barrens sediments. The characteristic species common to both are rounded purplish zircons and greenish tourmaline (rounded schorl grains with authigenic elbaite outgrowths)—the latter, because of its peculiar varietal features, is particularly significant. Zircon is present in the Mt. Ragged metasediments but the characteristic tourmaline is not.

Until more detailed field work can be carried out to elucidate the relationship between the granitic rocks and the metasediments of the Barrens belt the latter must, on the basis of the petrographic evidence, be regarded as an easterly extension of the Stirling Range beds and therefore of the Proterozoic age. The main difference between the Barrens and the Stirling Range metasedimentary sequences lies in the concordant basic intrusions in the former. Interbedded basic lavas and sills are common in the Nullagine System (Prider, 1948, p. 65) and the greenstones of the Barrens belt may be regarded as the representatives of this Nullagine vulcanism.

2. *The origin of the gneisses.*

The gneisses are a migmatitic complex of para-gneisses, various basic granulites and granitic gneiss with abundant pegmatite-aplite veins. The marked variation in character across the strike strongly indicates that these rocks were originally sediments or sediments with interbedded basic volcanics which have subsequently been granitized.

There can be no doubt, in view of the mineralogy and chemical composition, that the alumina-rich and calc-silicate gneisses described under II in the petrography section of this paper are of metasedimentary origin and that they represent residuals of the original sedimentary terrain which have escaped complete granitization.



Text fig. 5.

Normative variation diagrams of gneisses and granites from the South Coast. Circles represent acid gneisses and letters A, B. etc., refer to analyses in Table II; triangles represent basic bands in the acid gneisses and letters A, B, etc., refer to analyses in Table IV; dots represents the younger granites and letters A, B, etc., refer to analyses in Table V.

The origin of the basic bands in the gneiss is not, however, so evident. Plotting the analyses of these rocks (set out in Table IV) on the normative variation diagram of Brammall (1933, p. 101) we see (text fig. 5) that they all lie within the igneous field and are centred about the basalt field. This in itself is not proof of their igneous origin but indicates the close geochemical similarity of these basic granulites to the basic igneous rocks. Carroll (1940, p. 169) has suggested that the basic bands in the gneisses of Cape Leeuwin (which are very similar to those in the region under review) were originally tuffs but this cannot be substantiated because of the complete obliteration in these coarse basic granulites of any original textures and structures which may yield a clue regarding their origin.

Attention has been drawn in the petrographic section of this paper to the petrographic and chemical similarity between :—

(a) The plagioclase-hornblende gneisses of the South Coast strip and the hornblende-plagioclase granulite lenses in the gneisses of the Toodyay District which Prider considers (1944, p. 121) to be derived from meta-basic igneous rocks.

(b) The plagioclase-hornblende-two pyroxene granulites of the South Coast strip and the basic charnockites from the Dangin area which are also considered by Prider (1945, p. 169) to be meta-basic igneous rocks.

In view of the complete obliteration of original structures in these rocks by recrystallisation under deep-seated conditions, chemical composition is our sole clue to their origin and on this basis they are most probably the remnants, which have escaped granitization, of original basic igneous rocks.

The acid gneisses vary in composition and mineralogy from aplogneiss of group I G. to gneisses containing similar associations of femics to those present in the associated basic bands. Plotting the acid gneisses on Brammall's normative composition diagram they are found (text fig. 5) to have a wide spread and occur in the sedimentary, metamorphic and igneous fields as set out by Brammall (1933, p. 101). Much of the quartz in these gneisses occurs in rounded grains poikiloblastically enclosed in microcline and orthoclase and these are interpreted as remnants of original water-worn sand grains. Most of the acid gneisses are characterised by the presence of turbid plagioclase and water-clear microperthitic microcline or orthoclase, the potash felspar being clearly the latest mineral formed. Moreover myrmekite is a constant feature of these rocks. These features point to the late introduction of alkalies, particularly potash, into the gneisses which appear to be the products of metasomatism and migmatization (as set out by MacGregor and Wilson, 1939, p. 212) of pre-existing arkosic-, clayey-, and calcareous-, sediments and associated basic igneous sills or flows.

3. *The genesis of the granites.*

There are two main types of granite, both of which are best described as adamellites the older is the coarse porphyritic adamellite, the younger is a fine even-grained adamellite intrusive into the porphyritic adamellite. Both are igneous in the sense that they have been intruded and show platy flow structures in the endogenous contact zones. Plotting the analyses that are available (Table V, analyses A, B and C) on Brammall's normative variation diagram they are seen (text fig. 5) to fall in the " metamorphic " field.

Considering firstly the coarse porphyritic adamellites we find the following significant features :—

(i) The femic constituents (biotite, hornblende, clinopyroxene and hypersthene) are similar to the femic associations in the gneisses and associated basic granulites and moreover these minerals tend to occur in clotted aggregates which are best explained as micro-xenoliths derived from the older gneisses. Spindle-shaped xenoliths up to several inches long of hornblende granulite which are present in some of these adamellites lend support to this suggestion as does the marked concentration in these femic clots of the accessory minerals apatite and sphene.

(ii) The microcline " phenocrysts," containing as they do enclosures of the various minerals and mineral aggregates of the groundmass, are actually porphyroblasts which have developed in the rock during a period of metasomatic granitization.

(iii) The parallel alignment of the microcline porphyroblasts indicates either : (a) granitization in situ under directed stress conditions or (b) mobilization of the granitized products and its intrusion as a crystal mush during which movement a platy flow alignment of the porphyroblasts has been produced. In view of the occurrence at Point William, Albany, of a narrow (1 ft. wide) dyke of the porphyritic adamellite with the porphyroblasts aligned parallel to the walls the latter is the preferred hypothesis.

The porphyritic granites therefore appear most probably to be the mobilized products of the granitization of the older charnockitic gneisses. On the normative variation diagram (text fig. 5) they are more remote from the An-Fem pole than the gneisses and associated basic granulites from which they were developed and this is in keeping with the findings of MacGregor and Wilson (1939).

So far as the younger fine-grained adamellites are concerned all that can be said is that they are magmatic intrusives dyke (as evidenced by faint platy flow structures) rather than replacement dykes and that in composition they are more siliceous and more alkalic than the porphyritic adamellites. They could therefore have crystallised from a magma resulting from a filter-press action on the porphyritic granite crystal-mush magma.

4. *The Greenstones.*

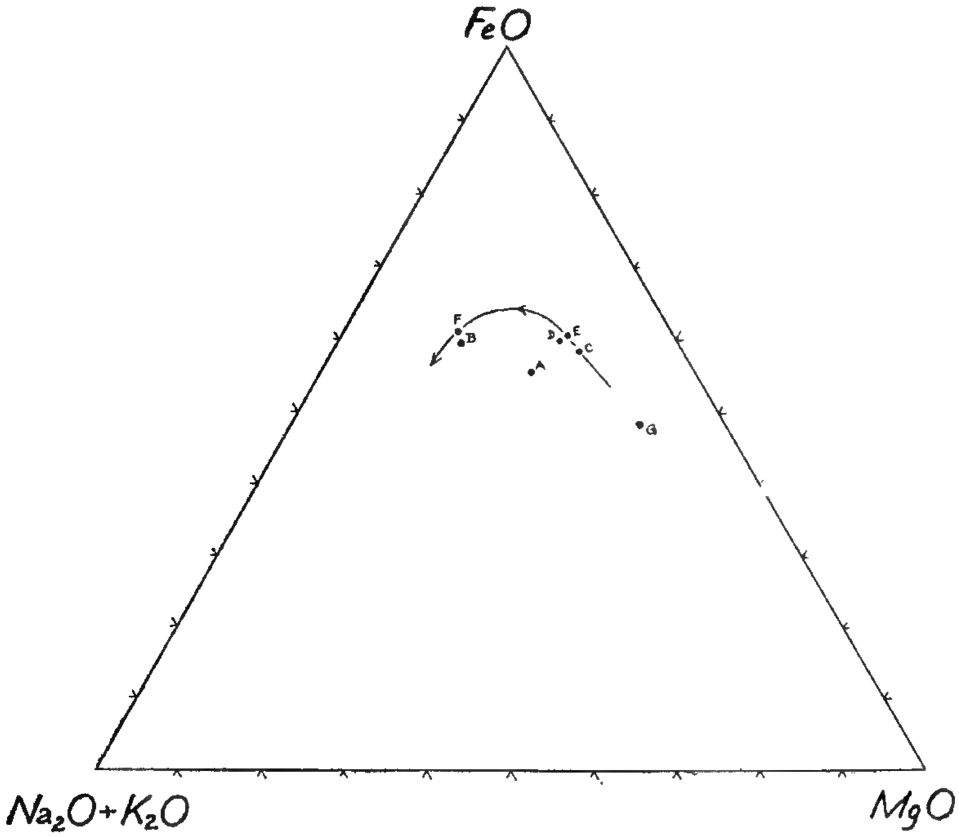
There are three main groups of greenstones present in the area examined—the hornblende granulite bands in the Archaean gneisses, the concordant uralitized and sheared quartz dolerites associated with the metasediments of the Phillips and Hamersley Rivers sections, and the quartz dolerite dyke suite. The origin of the former has already been considered under (2) above.

The sheared and uralitized quartz dolerite sills of the Phillips and Hamersley Rivers sections antedate the overthrust movements which have affected the Nullagine sediments and are considered therefore to be older than the quartz dolerite dyke suite. They are now completely uralitized and saussuritized and petrographically resemble the uralitic quartz dolerites of the Younger Greenstone Series of Kalgoorlie, but in view of their association with sediments which are now considered most probably to belong to the Nullagine System they are best regarded as representatives of the Nullagine vulcanism of which we have evidence in other parts of the State (Prider, 1948, p. 65).

The late-Nullagine dolerite dykes vary from olivine dolerites through quartz dolerites to quartz diorite. The olivine dolerites are of two varities : (i) Undersaturated even medium textured rocks and, (ii) saturated microporphyritic aphanitic rocks. Unfortunately no chemical analysis is available of the former but the latter, in spite of the olivine present, is a saturated rock almost identical in composition with the normal quartz dolerite. The microporphyritic olivine dolerites occur in the chilled margins of the quartz dolerite dykes and the presence of olivine is due to the prevention of the olivine-pyroxene reaction so that the early crystallizing olivine, which would normally disappear by reaction, is retained in the rock.

The almost identical chemical composition of the uralitized and unaltered quartz dolerites (*see* Table VI, analyses C and D) indicates their co-magmatic origin and also that uralitization has not produced any appreciable change in chemical composition.

The " quartz diorite " is the most acid member of the quartz dolerite suite. This rock, the origin of which has been discussed in the petrographic section of the paper, is a sodic and siliceous end-phase differentiate of the quartz dolerite magma. A plot of the $FeO/MgO/Na_2O+K_2O$ ratios of the basic dykes of the Strip (fig. 6) indicates that there is no appreciable enrichment of FeO in this end-phase differentiate with respect to the normal quartz dolerite but there is a marked increase in the alkalies and silica. This, as has been noted by Wager and Deer (1939) and Walker and Poldervaart (1949, p. 656) is characteristic of the final stage in the fractional crystallization of basaltic magma.



Text fig. 6.

Quartz dolerite suite of South Coast: FeO-MgO-(Na_2O+K_2O) ratios showing differentiation trend. Letters refer to analyses in Table VI. Analysis G is quartz dolerite from Toodyay.

Although the microporphyritic olivine dolerites, quartz dolerites and " quartz diorite " can be matched with members of the basic dyke suite throughout South-Western Australia, the porphyritic dolerite and its chloritized equivalent from Pt. Hillier appear to be abnormal. Apart from the porphyritic character the abnormal chemical characteristics are the high TiO_2, P_2O_5, K_2O and Al_2O_3 content. These dolerites, which are characterized by a comparatively deep-coloured titaniferous augite, bear the same relations to the country rocks as do the normal quartz dolerites and the reason for the marked difference is not apparent.

There can be little doubt that the quartz dolerite suite of the South Coast is co-magmatic with the late-Nullagine basic dykes (Prider, 1948, p 67) throughout the entire West Australian Pre-Cambrian shield.

5. *Changes in regional strike.*

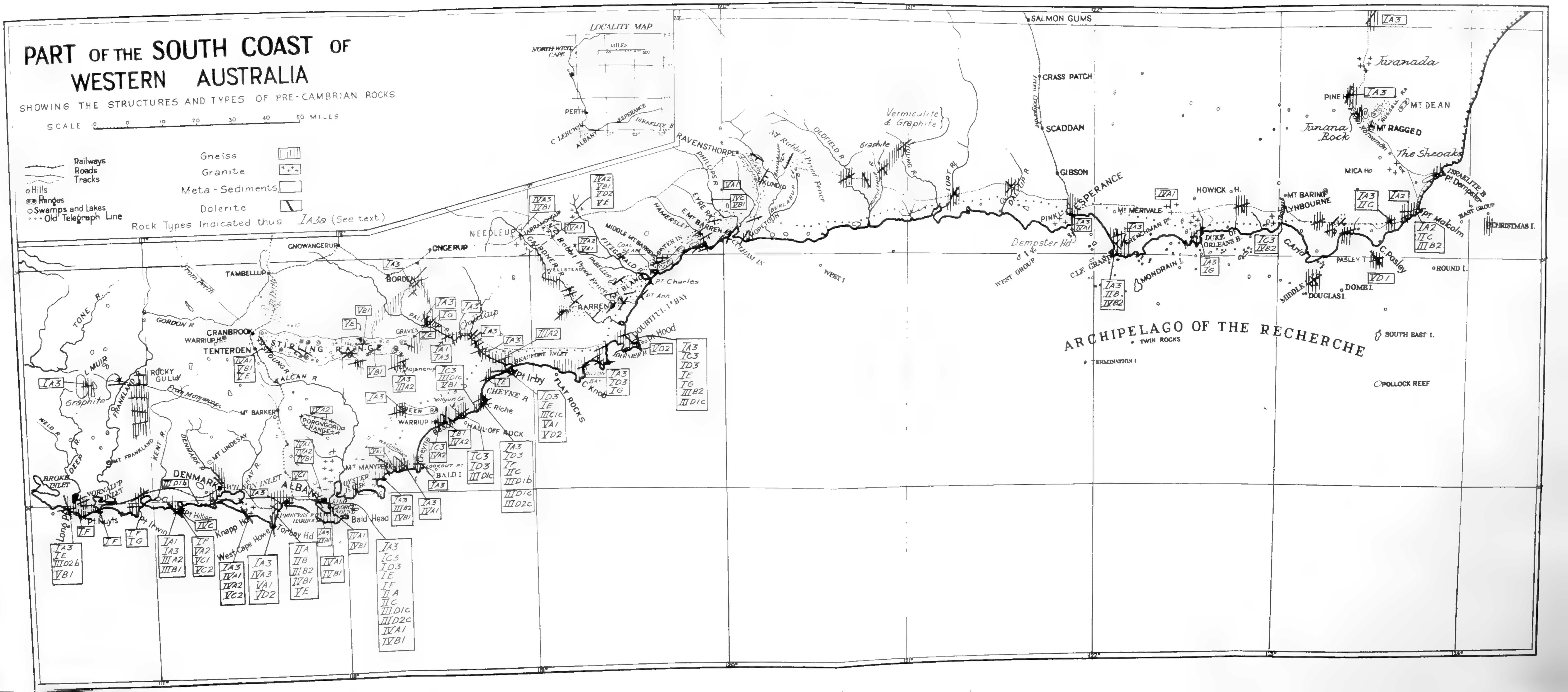
We have no explanation to offer for the sudden changes in regional strike.

VII. CONCLUSIONS.

The oldest rocks in the area examined are the Mt. Ragged metasediments and the remnants of metasediments and basic igneous rocks which occur in the gneisses and which are now represented by a variety of coarse gneissic granulites and banded gneisses. The main structures in these Archaean rocks trend E.N.E. in marked contrast to the N.W. trend throughout the greater part of

the Western Australian Pre-Cambrian shield and there is apparently a major break in the Pre-Cambrian structure along an E-W line situated approximately fifty miles north of the South Coast. These Archaean gneisses, largely of charnockitic type, are essentially a granitized and migmatized group of sediments and associated basic igneous rocks, similar in many respects to those of the south-western section of the Western Australian shield. They have been intruded by granites which are considered to be palingenetically derived from the older gneisses. Proterozoic rocks are represented by shallow water sediments—the Stirling Range beds and their easterly extension in the Mt. Barrens area—which in the Hamersley and Phillips River carry doleritic sills. In late-Nullagine times overthrust movements from the S.S.W. caused low grade metamorphism of these sediments. The final phase in the Pre-Cambrian history of this region was the intrusion of quartz dolerite and associated basic dykes which are considered to be co-magmatic with the late-Nullagine quartz dolerite suite of the remainder of the West Australian Pre-Cambrian shield.

Much more detailed work both field and petrological is required before the structure and origin of the rocks of the Strip can be completely elucidated. The preliminary petrographic work described in this paper has indicated that most of the gneisses and associated granitic intrusives appear to be represented in the vicinity of Albany and we suggest that for a detailed investigation of the South Coast Archaean rocks the easily accessible exposures near Albany would repay detailed mapping and petrographic study.



PART OF THE SOUTH COAST OF WESTERN AUSTRALIA
SHOWING THE STRUCTURES AND TYPES OF PRE-CAMBRIAN ROCKS
SCALE 0 10 20 30 40 50 MILES
Railways
Roads
Tracks
Hills
Ranges
Swamps and Lakes
Old Telegraph Line
Gneiss
Granite
Meta - Sediments
Dolerite
Rock Types Indicated thus IA3a (See text)
LOCALITY MAP
NORTH WEST CAPE
PERTH
C LEEUWIN
ALBANY
ESPERANCE
ISRAELITE B
SALMON GUMS
CRASS PATCH
SCADDAN
GIBSON
ESPERANCE
RAVENSTHORPE
KUNDIP
HOPETOUN
Vermiculite & Graphite
OLDFIELD R
LORT R
DALYUP R
Juranada
PINE
MT DEAN
MT RAGGED
Junana Rock
The Sheoaks
MICA Ho
ISRAELITE B
Pt Dempster
Pt Malcolm
C Pasley
HOWICK H.
MT BARING
LYNBOURNE
MT MERIVALE
DUKE ORLEANS B.
CAPE ARID
PASLEY I.
DOME I.
DOUGLAS I.
MIDDLE I.
MONDRAIN I.
WEST GROUP
WEST I
Dempster Hd
CHRISTMAS I.
ROUND I.
ARCHIPELAGO OF THE RECHERCHE
TWIN ROCKS
TERMINATION I
SOUTH EAST I.
POLLOCK REEF
MIDDLE MT BARREN
EYRE RA
MT BARREN
HAMERSLEY
FITZGERALD R
PHILLIPS R
NEEDLEUP
GNOWANGERUP
ONGERUP
BORDEN
GAIRDNER R
Pt Charles
Pt Ann
DOUBTFUL I. BAY
Pt Hood
BREMER B.
TAMBELLUP
From Perth
GORDON R
TONE R
CRANBROOK
WARRIUP H.
TENTERDEN
STIRLING RANGE
KALGAN R
MT BARKER
PORONGORUP RANGE
L MUIR
ROCKY GULLY
Graphite
FRANKLAND R
KENT R
DENMARK R
MT LINDESAY
MT FRANKLAND
WELD R
DEEP R
BROKE INLET
NORNALUP INLET
DENMARK
WILSON INLET
ALBANY
KING GEORGE SOUND
PRINCESS ROYAL HARBOUR
Bald Head
Torbay Hd
West Cape Howe
Knapp Hd
Pt Hillier
Pt Irwin
Pt Nuyts
Long Pt
OYSTER H.
MT MANYPEAKS
BALD I
CHEYNE B
CHEYNE R
C Riche
HAUL-OFF ROCK
Pt Irby
FLAT ROCKS
C Knob
BEAUFORT INLET
WARRIUP H

Plate II.

Fig. 1.

Sheared quartzite (13316) from Pt. Ann showing lenticular character and undulose extinction of the quartz. Nicols crossed. x50.

Fig. 2.

Rounded quartz grain (in centre of field) enclosed in orthoclase which is replacing plagioclase. Nicols crossed. x50.

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2.—RECENT SEDIMENTATION, PHYSIOGRAPHY AND STRUCTURE OF THE CONTINENTAL SHELVES OF WESTERN AUSTRALIA

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ABSTRACT

Some 400,000 square miles of shelf 24 to 250 miles wide and 4,000 miles long, are divided into Sahul, Rowley, Dirk Hartog, Rottnest, Recherche and Eucla Shelves. Morphology shows very distinct terracing with a transverse division into an inner and outer shelf, the latter often having a steeper gradient. Shelf sediments are dominantly clastic, calcareous and organogenic, being derived from fragmental mollusca, corals, bryozoa, foraminifera, algae, etc.; there are smaller amounts of insoluble residual sands (mainly quartz), glauconite, fine terrigenous debris (clay) and chemically precipitated calcareous muds. The whole shelf area constitutes a single mega-facies, characterised by slow uniform sedimentation of calcareous and residual deposits. There are few macro-fossils except in local bioherms and biostromes and in very restricted littoral, lagoon, bay, and estuarine areas. Foraminifera are widespread. Such a mega-facies must be related to an arid, ancient landmass of low relief.

Correlation of mainland tectonics with shelf and adjacent ocean floor morphology shows direct relationship between sedimentary basins, broad concave sectors of shelves and deep sea basins (negative regions) and between positive tectonic blocks on the continent, shallow "rises" on the shelf and deep sea ridges. This transition suggests that the difference between the surface crust of the continent and ocean floor here is one of degree, not kind. Gravity anomalies of -140 mgl. (isostatic) on Rottnest Shelf and -150 mgl. on Exmouth Rise suggest considerable cumulative marginal subsidence. Scattered seismicity here indicates however only slight mobility at present. Palaeogeographic evidence suggests repeated subsidences along the western continental border since Pre-Cambrian. Origin of shelves is complex: different sectors are dominated by different factors, which include variable degrees of tectonic deformation and sedimentation, susceptibility to marine erosion, and the universal effects of eustatic changes of sea-level Thus some shelves are dominantly sedimentary wedges, others are mainly erosion platforms, but all are compound.

I.—INTRODUCTION

The question of the origins of continental shelves is still a controversial issue in geology. Many hypotheses have been advanced to account for this ubiquitous feature of the continents. The heterogeneous nature of the rocks and structure of the shelves is clearly demonstrated by the large number and variety of these hypotheses (for recent summaries, see Shepard, 1948, and Kuenen, 1950, a and b). Few workers on this subject have fully realized that no one hypothesis can explain the origin of every continental shelf. In this paper the writers have been able to show that a positive relationship exists between the morphology of the continental shelves, the adjacent ocean floor and the Pre-Cambrian basement of the landmass of Western Australia (see text-fig. 1).

The coastline of Western Australia is 5,200 miles long and its continental shelves cover an area of approximately 400,000 square miles. The present paper is essentially based upon a collation of the shelf soundings and sediments from the Admiralty hydrographic charts, which have then been correlated with the geomorphology and tectonics of the adjacent continent and ocean basins. Field work has been restricted for a variety of reasons, the main ones being the vast area covered by the continental shelves, and the lack of a ship suitably equipped and with the time available for sounding and bottom sampling. Some samples of the sea floor on the shelf and slope west of Fremantle and some from the Eucla shelf in the vicinity of 125° E. longitude, which were dredged by the R.R.S. *Discovery II* on her 1950 voyage to the Southern Ocean, have been made available to us to study. Other samples have been collected by one of us (M.A.C.) during short excursions on Fisheries Department vessels out of Fremantle, and on a trip from Fremantle to Albany on the lighthouse tender s.s. *Cape Otway* in February, 1951. Detailed analyses of these and the *Discovery* samples will be communicated in a later paper. The analysis of these samples has helped to elucidate the sediment notations on the Admiralty charts which have been collated in text-figs. 6-8.

A study of this sort may, it is hoped, be valuable in varied fields: fishery researchers require information of shelf bottom topography and material; petroleum geologists are becoming increasingly attracted by continental shelves as potential oilfields and students of sedimentation may find interest in the relatively "abnormal" environment of slow deposition off an arid continent; from the viewpoint of fundamental geotectonics and geophysics the relationship between continents and ocean basins is still an unsolved problem on which this paper may shed some light.

II.—PHYSICAL OCEANOGRAPHY

1.—Tides

Unfortunately very little is known of the tides on the West Australian coast, only two detailed analyses having been made. Curlewis (1916) analyses readings from Fremantle and Port Hedland and Bennett (1939) gives a more comprehensive treatment of the Fremantle data. Provisional analyses by Admiralty surveyors provide us with characteristics for a number of other points along the coast. Some of the physiographic effects were noted by Fairbridge (1950a). The spring range at Fremantle is 3 feet, but this is augmented by an annual rise and fall of mean sea-level of 2.26 feet. The tides on the south coast are of the same order, but they increase in range northward from Geraldton to Wyndham. The tides at Port Hedland have a spring range of 22.5 feet and neap range of 7.5 feet. At Derby there is a spring range of 36 feet. Curlewis relates the greater tidal ranges to the increasing width and shallowness of the continental shelf here.

2.—Winds

There are two main winds which affect Western Australia south of the Tropic of Capricorn, the south-east trades and the westerlies. The trade winds affect most of this area during the summer but move north of latitude 30°S. in the winter. They are dry winds, having traversed an arid continent. The belt of westerlies only affects the extreme south-west in the summer but moves as far north as 30°S. in the winter; these winds gather moisture over the Indian Ocean and bring a reliable winter rainfall to the south-western corner of Australia.

In the north-western portion of the State the winds are monsoonal. The wet monsoon is brought by north-west winds, which blow during the southern summer from December-March. They sweep in from the direction of Java, across the north-east Indian Ocean and in the elevated areas of the Kimberley lead to a heavy summer rainfall. There are also seasonal cyclonic winds (hurricanes) locally known as "willy-willies" which originate in the Timor Sea and follow the coast southward exhibiting their greatest energy between latitudes 20° and 22°S. They may, on occasions, cross the continent to the Great Australian Bight (Admiralty "Pilot", 1934; Jutson, 1934).

3.—Ocean Currents

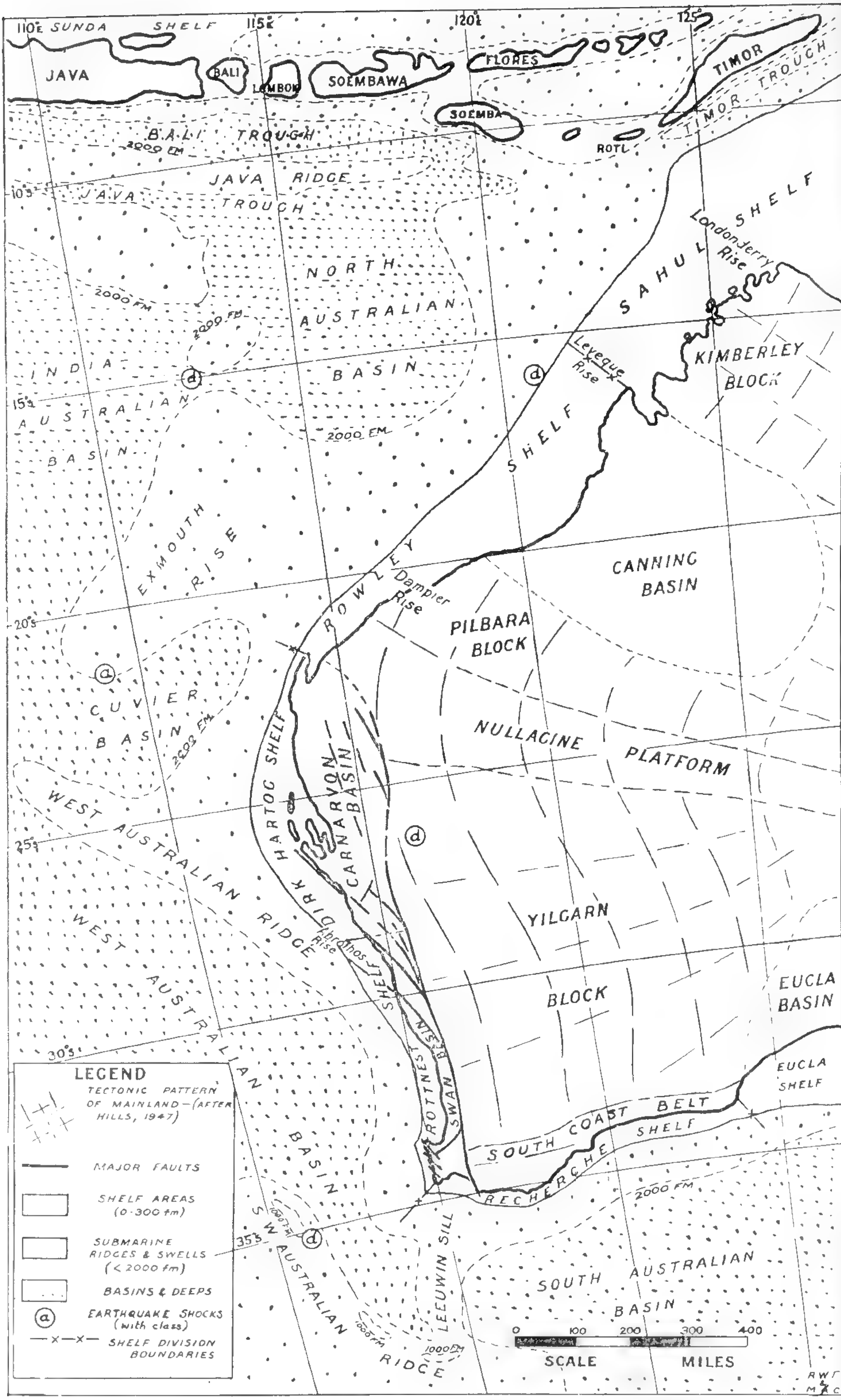
Relatively little is known, in detail, of the ocean currents in the eastern part of the Indian Ocean. Between February and and March, there is a drift to the north along the west coast of Australia and a drift to the west along the south coast (Schott, 1935; see also Sverdup *et. al.* 1942). The northerly drift divides into two off North-West Cape, one part joining the South Equatorial Current, the other part continuing along the north-west coast across the Sahul Shelf and into the Arafura Sea, with variable sets close inshore. In the winter months (July, August), the west wind drift across the Indian Ocean reaches the south-west coast and follows the southern shores of the continent, reversing the whole system of currents. The information available from the northern coasts of Australia suggest that in the winter months south-east winds cause a reversal of current in the north-east Indian Ocean and that water from the Pacific Ocean may cross the Arafura Sea.

III.—MORPHOLOGY OF THE CONTINENTAL SHEVLES

The following classification of Western Australian shelves is based on area, width, declivity of the shelf, inclination of the continental slope, and tectonic consideration of the adjacent ocean floor and continental mass. Structural boundaries have been followed as far as possible.

1.—The Sahul Shelf (Molengraaff and Weber, 1919; Fairbridge, 1953)

This shelf (see text-fig. 1) extends from Cape Leveque (16°20′S. 123°E.) seawards to 15°S. 121°E. and north-eastward to Melville Island (131°E.), covering an area of 160,000 square miles.


110°E SUNDA SHELF
115°E
120°E
125°
JAVA
BALI
LOMBOK
SOEMBAWA
FLORES
TIMOR
TIMOR TROUGH
SOEMBA
ROTI
BALI TROUGH
2000 FM
JAVA RIDGE
10°S
JAVA TROUGH
NORTH AUSTRALIAN BASIN
SAHUL SHELF
Londonderry Rise
INDIA AUSTRALIAN BASIN
15°S
Leveque Rise
KIMBERLEY BLOCK
SHELF
EXMOUTH RISE
ROWLEY
Dampier Rise
CANNING BASIN
PILBARA BLOCK
20°S
CUVIER BASIN
NULLACINE PLATFORM
HARTOG SHELF
CARNARVON BASIN
WEST AUSTRALIAN RIDGE
25°S
DIRK
Abrolhos Rise
YILGARN BLOCK
WEST AUSTRALIAN BASIN
SHELF
EUCLA BASIN
30°S
ROTTNEST
SWAN BASIN
EUCLA SHELF
SOUTH COAST BELT
SHELF
RECHERCHE
LEGEND
TECTONIC PATTERN OF MAINLAND—(AFTER HILLS, 1947)
MAJOR FAULTS
SHELF AREAS (0-300 fm)
SUBMARINE RIDGES & SWELLS (< 2000 fm)
BASINS & DEEPS
EARTHQUAKE SHOCKS (with class)
SHELF DIVISION BOUNDARIES
35°S
SW AUSTRALIAN RIDGE
LEEUWIN SILL
1000 FM
SOUTH AUSTRALIAN BASIN
0 100 200 300 400
SCALE MILES
RWF
MAC

Text fig. 1.

It is 220 miles wide off Cape Londonderry (the Londonderry Rise) and is nearly horizontal in this area, the shelf edge at the coral Sahul Banks being only about 25 fathoms. The edge may, in places, extend down to 300 fathoms, as in the Browse depression. The continental slope is fairly steep and in the Timor Trough drops sharply to 2,000 fathoms.

Atolls or "drowned" coral banks are located on the lowest parts of the shelf edge (Teichert and Fairbridge, 1948). This shelf may be divided bathymetrically in two ways: normal to the coastline into an inner and an outer shelf with a step at 60 fathoms, and parallel into a series of rises and depressions. There are also a number of intermediate terraces at 3-5, 10-15, and 25-30 fathoms, which are locally cut by shallow submarine valleys.

2.—The Rowley Shelf (Fairbridge, 1953)

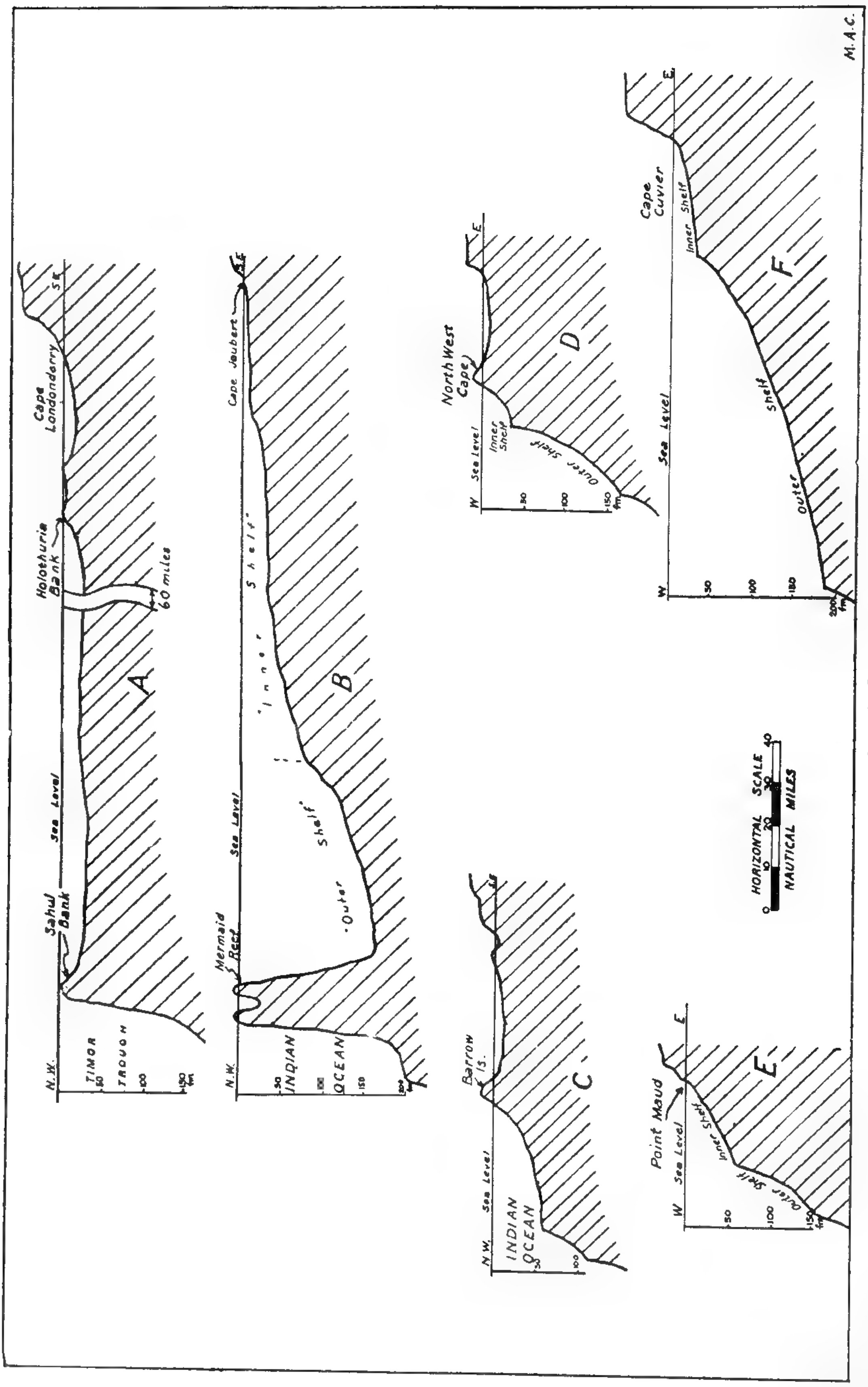
This shelf is named after the Rowley Shoals which are atolls rising near its outer edge. "Rowley Shelf" is preferred to "North-West Shelf" (of Krümmel, 1897) as it is better to name the shelves after a recognised geographical feature.

The Rowley Shelf is separated from the Sahul Shelf by the Leveque Rise, a morpho-tectonic boundary. The southern boundary at North-West Cape is convenient for here the shelf width is at its minimum (see text-fig. 1). The shelf has an area of 95,000 square miles. Its width and depth vary from 220 miles and 200-300 fathoms opposite Cape Jaubert to about 24 miles and 100 fathoms at North-West Cape. There is a distinct inner shelf (under 60 fathoms) which varies in width from about 110 miles off Cape Jaubert to 20 miles off Barrow Island and to 6 miles of North-West Cape (see profiles B, C and D, text-fig. 2). There also appears to be an intermediate platform around Barrow Island and the Monte Bello Islands.

3.—The Dirk Hartog Shelf

Fairbridge (1950b) called the shelf extending from North-West Cape southward the "West Coast Shelf." On the basis of tectonic and oceanographic considerations, it seems desirable, however, to make a two-fold division, the northern to be called the "Dirk Hartog Shelf." This extends from North-West Cape ($21\frac{1}{2}$°S. 114°E.) to a line joining North Islet of the Houtman's Abrolhos Group (28°S. $113\frac{1}{2}$°E.) to Shoal Point on the mainland. The southern boundary corresponds approximately with a broad platform, the Abrolhos Rise (see text-fig. 1). This shelf has an area of 30,000 square miles, and is named after Dirk Hartog Island at the entrance of Shark Bay. It is much narrower than the northern shelves just described. Its width in the north is about 24 miles, but reaches its maximum of approximately 110 miles between Cape Cuvier and Dirk Hartog Island where the outer limit is about 200 fathoms. Offshore soundings are very

widely scattered on this shelf so its edge can only be located within wide limits. The inner and outer shelf surfaces recognised on the Rowley Shelf are, however, easily discernible (see text-fig. 2, profiles D, E, and F), as well as certain shallower

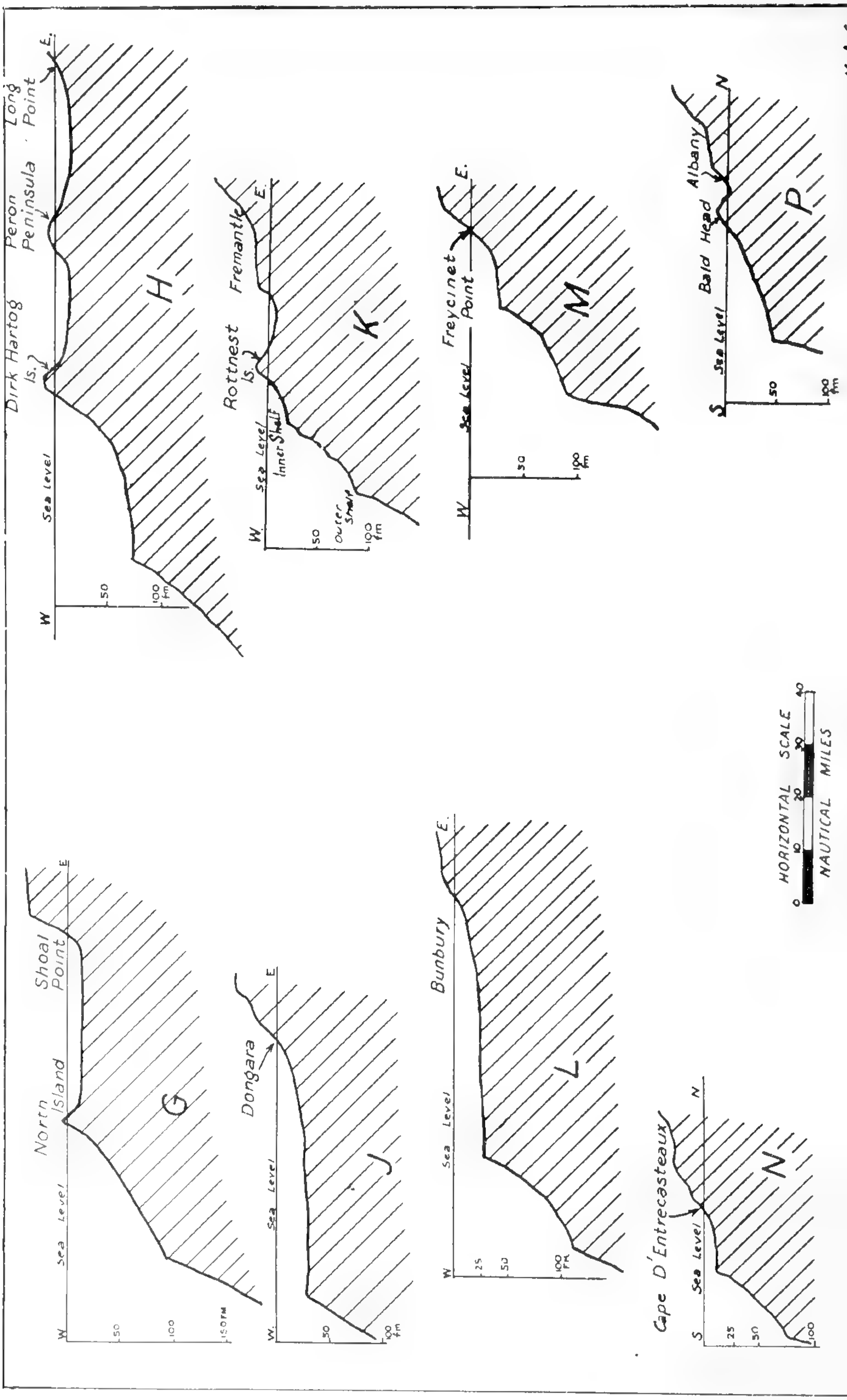


Text fig. 2.

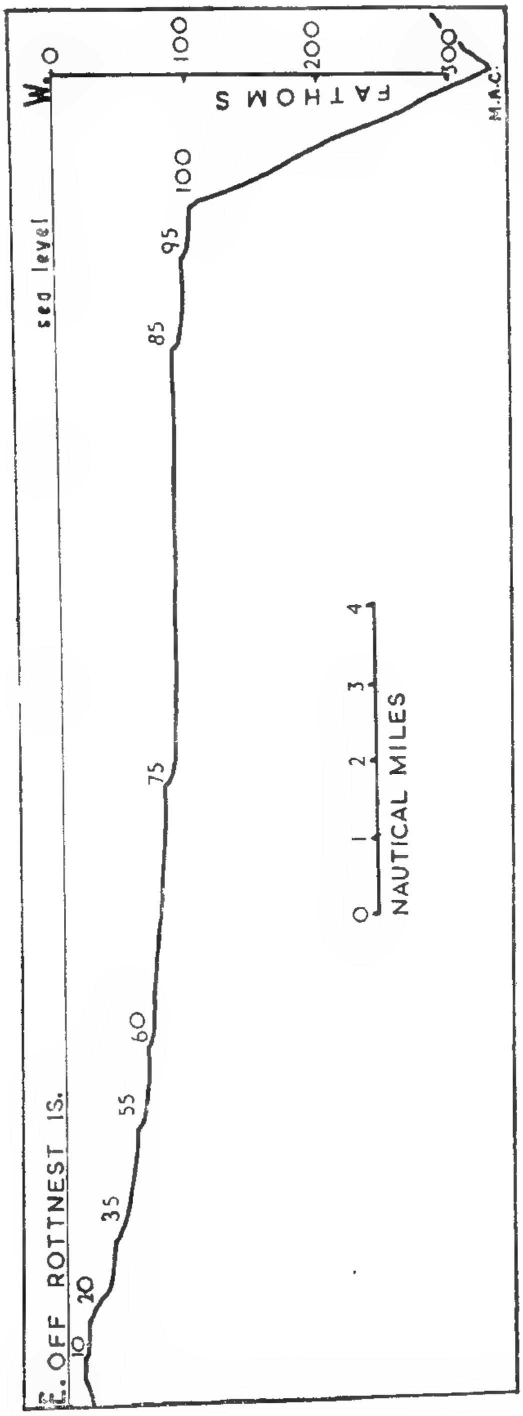
platforms—for example the floor of Shark Bay at 10-15 fathoms. The shelf appears to be symmetrical about an axis coinciding with latitude 25°S. where it reaches its maximum width and depth. The width and depth of the inner shelf varies from 10 miles and 40 fathoms at North-West Cape, to 20 miles and 60 fathoms at Maud Point; 25 miles and 55 fathoms at Cape Cuvier; 30 miles and 70 fathoms at Dirk Hartog Island and 37 miles and 30 fathoms at North Islet, the southern boundary. Here again there appears to be a correlation in width and depth between the inner and outer shelves.

4.—The Rottnest Shelf

Clarke (1926b) named the Rottnest Shelf after Rottnest Island which lies 10 miles west of Fremantle (32°S. 115½°E.). The shelf covers an area of 20,000 square miles and extends from North Islet of the Abrolhos Group to a line running south-west from Cape Leeuwin (34½°S. 115°E.). This is a narrow shelf. Its width varies only 30 miles over its total length, from 62 miles at North Islet to 32 miles at Rottnest. The inner and outer shelves are easily recognised as on the other shelves but are shallower than in the north. As mentioned in the previous section, an inner shelf can be recognised at North Islet (see profile G, text-fig. 3). At Dongara (see profile J) there is a clear inner shelf averaging 15-30 fathoms, but there are insufficient soundings to identify the outer shelf edge. At Rottnest, again, both inner and outer shelves may be recognised from chart data (see profile K). Recent echo-graphs recorded by the F.R.V. *Warreen* (see text-fig. 4) show far more detail than could be gleaned from the Admiralty wire soundings. It is clear that, superimposed on this broad subdivision of inner and outer shelf, there is a series of intermediate terraces or platforms: 3-5, 10-12, 20-25, 30-35, 55, 60, 75, 85, 95 and 100 fathoms. The 10-12 fathom platform between Fremantle and Rottnest Island is 14 miles wide (as indicated by Teichert 1950, p. 64); the inner shelf extends about 5 miles farther, dropping away to an outer edge at about 35 fathoms, while the outer shelf is steep at first becoming rather flat, 10-15 miles wide, and its outer edge is almost exactly at 100 fathoms. Southward the inner shelf broadens considerably and off Bunbury the inner shelf is 50 miles wide with the break at 35 fathoms. The outer shelf is 15 miles wide and the shelf edge is at 110 fathoms. Off Freycinet Point the inner shelf narrows to 13 miles and is bounded by the 35-fathom line. The outer shelf is slightly broader, and the shelf edge is at about 100 fathoms. A peculiar feature of the continental slope opposite Rottnest Island is a semi-circular platform about 10-15 miles wide (centred on 32°S. 115°E.) at 300-400 fathoms depth forming a lobe projecting from the continental slope; on its north side there appears to be a "submarine valley" of 700-1200 fathoms depth. Although the head of this "valley" lies approximately opposite the mouth of the Swan River, there is no sign of a valley across the Inner Shelf, but traces of it may perhaps be discerned in the Outer Shelf. Systematic soundings of this feature are still awaited.



Dirk Hartog Is.
Peron Peninsula
Long Point
Sea Level
W
E.
50
100 fm
H
Rottnest Is.
Fremantle
Sea Level
Inner Shelf
Outer Shelf
W.
E.
50
100 fm
K
Freycinet Point
Sea Level
W
E.
50
100 fm
M
Bald Head
Albany
Sea Level
S
N
50
100 fm
P
M.A.C.
North Island
Shoal Point
Sea Level
W
E
50
100
150 FM
G
Dongara
Sea Level
W.
E
50
100 fm
J
Bunbury
Sea Level
W
E.
25
50
100 FM
L
Cape D'Entrecasteaux
Sea Level
S
N
25
50
100
N
HORIZONTAL SCALE
NAUTICAL MILES
0
10
20
30
40

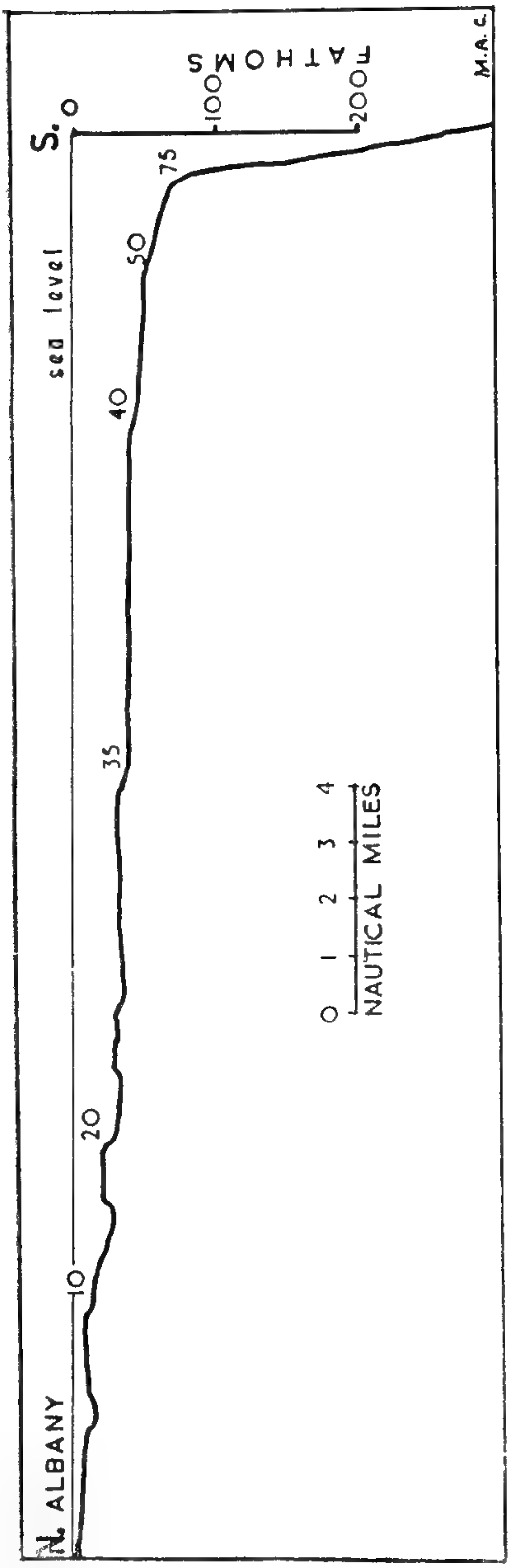


Text fig. 4.

5.—The Recherche Shelf

This shelf borders the south coast from Cape Leeuwin to Israelite Bay, approximately 33½°S. 124°E. It covers an area of 25,000 square miles and takes its name from the Recherche Archipelago, a group of rocky islets situated on its eastern part. It is a comparatively narrow shelf of fairly uniform width, 24 to 36 miles. At Cape d'Entrecasteaux the inner shelf is 12 miles

wide with a uniform depth of 25 fathoms almost to the coastline; the outer shelf here is also 12 miles wide, the edge being at about 90 fathoms. The continental slope has an average declivity of 1 in 12.



Text fig. 5.

From Albany southwards the shelf is very irregular for 15 miles or more, showing traces of 10-15, 20 and 35 fathom platforms. Then there is a very flat platform of 40 fathoms for 6 miles, followed by a narrower platform to 50 fathoms (2 miles) and another (2 miles) to the shelf edge at 75 fathoms, where it drops into the South Australian Basin with a slope of about 1 in 10 (see text-fig. 5).

In the latitude of the Recherche Archipelago most of the steep coast and islands (up to 700 ft. or so) rise abruptly from 20 or 35 fathom platforms which extend for 20 miles or so and after a steep drop flatten to another platform of 45-50 fathoms. The shelf edge may be at about 60 fathoms.

6.—*The Eucla Shelf*

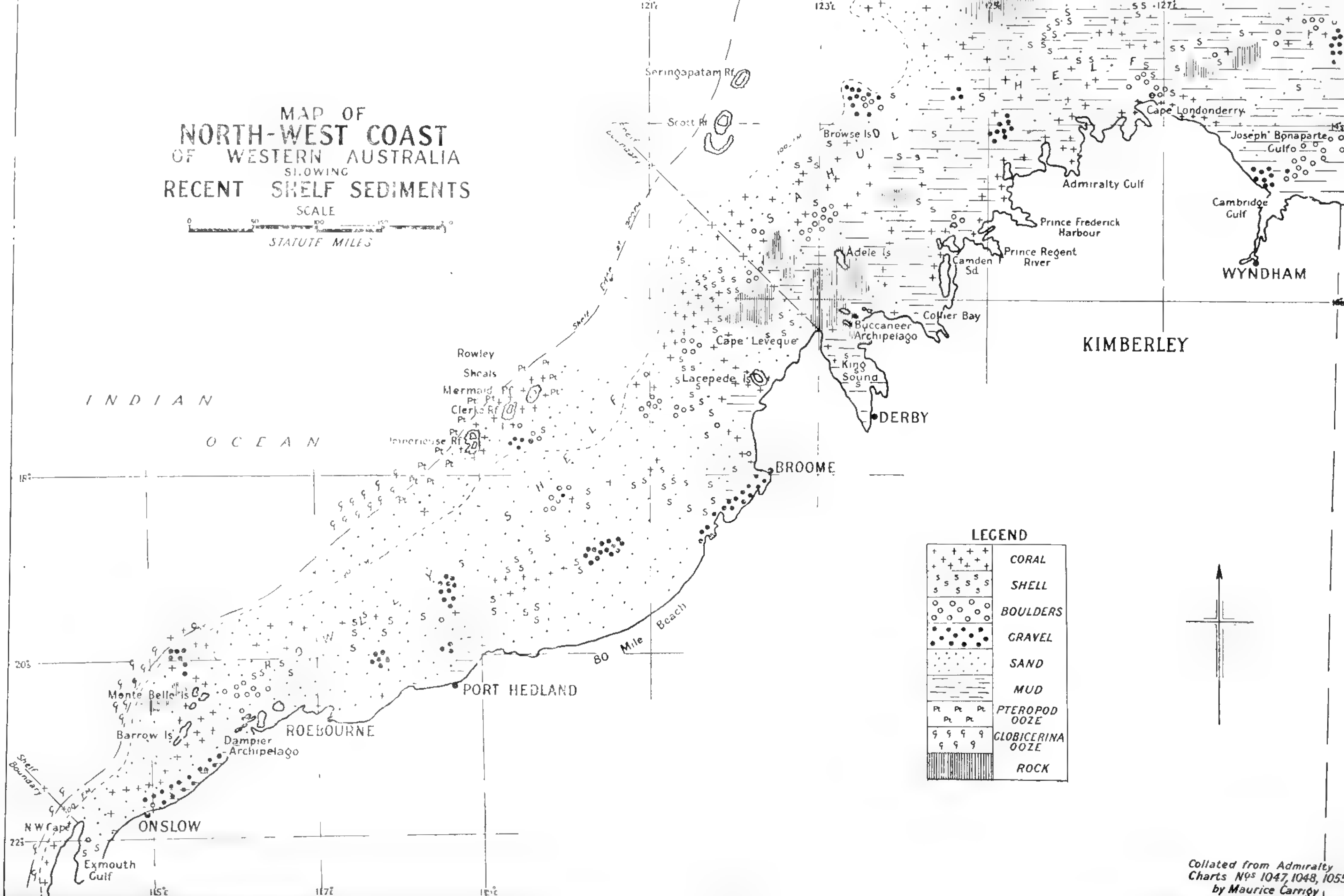
The Eucla Shelf has an area of 65,000 square miles and extends from Israelite Bay to Fowlers Bay (32°S. 132½°E.) in South Australia. It forms the floor of the inner part of the Great Australian Bight. It reaches its maximum width of about 120 miles near the meridian of 131°E. longitude, and tapers off at either end to narrow shelves. Soundings are very scarce in this area but the continental slope appears to be very steep, dropping very rapidly to over 2,000 fathoms in the South Australian Basin. Serventy (1937) states that the shelf edge is at 70 fathoms.

IV.—SEDIMENTS AND SEDIMENTATION OF THE SHELVES

1.—*Distribution*

The distribution of sediments on the continental shelves of Western Australia has been collated from the notations on the British Admiralty hydrographic charts, controlled, where possible, by personal collections and laboratory examination (see text-figs. 6-8). The hydrographer's classification of sediments is not as precise as one could wish, but further sampling would probably not alter the boundaries of the major divisions to any great extent.

The gravel, sand, and mud indicated on the hydrographic charts of eastern North America have been shown by Shepard and Cohee (1936) to correspond fairly closely to a geologist's megascopic description of a hand specimen without resort to sieve analysis. The "coral" shown on the chart is, however, less reliable and may indicate living coral, dead coral, or coral-like organisms such as hydrocorallinae and bryozoa (Fairbridge, 1950b). During the s.s. *Cape Otway* trip one of us (M.A.C.) took the opportunity of testing this and it was found that specimens of *Lithothamnion*, bryozoa and in fact most calcareous organic material was described by the officers and seamen as "coral." In general, that shown on the chart north of the Abrolhos is thought to be true coral debris from living reefs, and that south of the Abrolhos is believed to be either dead sub-fossil



MAP OF
NORTH-WEST COAST
OF WESTERN AUSTRALIA
SHOWING
RECENT SHELF SEDIMENTS
SCALE
STATUTE MILES
INDIAN
OCEAN
Seringapatam Rf
Scott Rf
Browse Is
Rowley
Shoals
Mermaid Rf
Clerke Rf
Imperieuse Rf
Adele Is
Cape Leveque
Lacepede Is
Buccaneer Archipelago
King Sound
DERBY
BROOME
Collier Bay
Camden Sd
Prince Regent River
Prince Frederick Harbour
Admiralty Gulf
Cape Londonderry
Joseph Bonaparte Gulf
Cambridge Gulf
WYNDHAM
KIMBERLEY
80 Mile Beach
PORT HEDLAND
ROEBOURNE
Dampier Archipelago
Barrow Is
Monte Bello Is
ONSLOW
N W Cape
Exmouth Gulf
Shelf Boundary
LEGEND
CORAL
SHELL
BOULDERS
GRAVEL
SAND
MUD
PTEROPOD OOZE
GLOBIGERINA OOZE
ROCK
Collated from Admiralty Charts Nos 1047, 1048, 1055 by Maurice Carrigy

coral (relics of warmer climatic stages in the Pleistocene or early Recent) or colonies of bryozoa (Fairbridge, 1950a). Nevertheless, in the region of Cape Leveque and the Lacepede Islands, off the Kimberley, there are also extensive bryozoan reefs, marked "coral" on the chart (Basset-Smith, 1899).

2.—Sedimentation

The distribution of sediments as shown in the text-figs. 6-8 may be separated into three major divisions:—

(*a*) Areas of moderate terrigenous sedimentation;

(*b*) areas of little active terrigenous sedimentation;

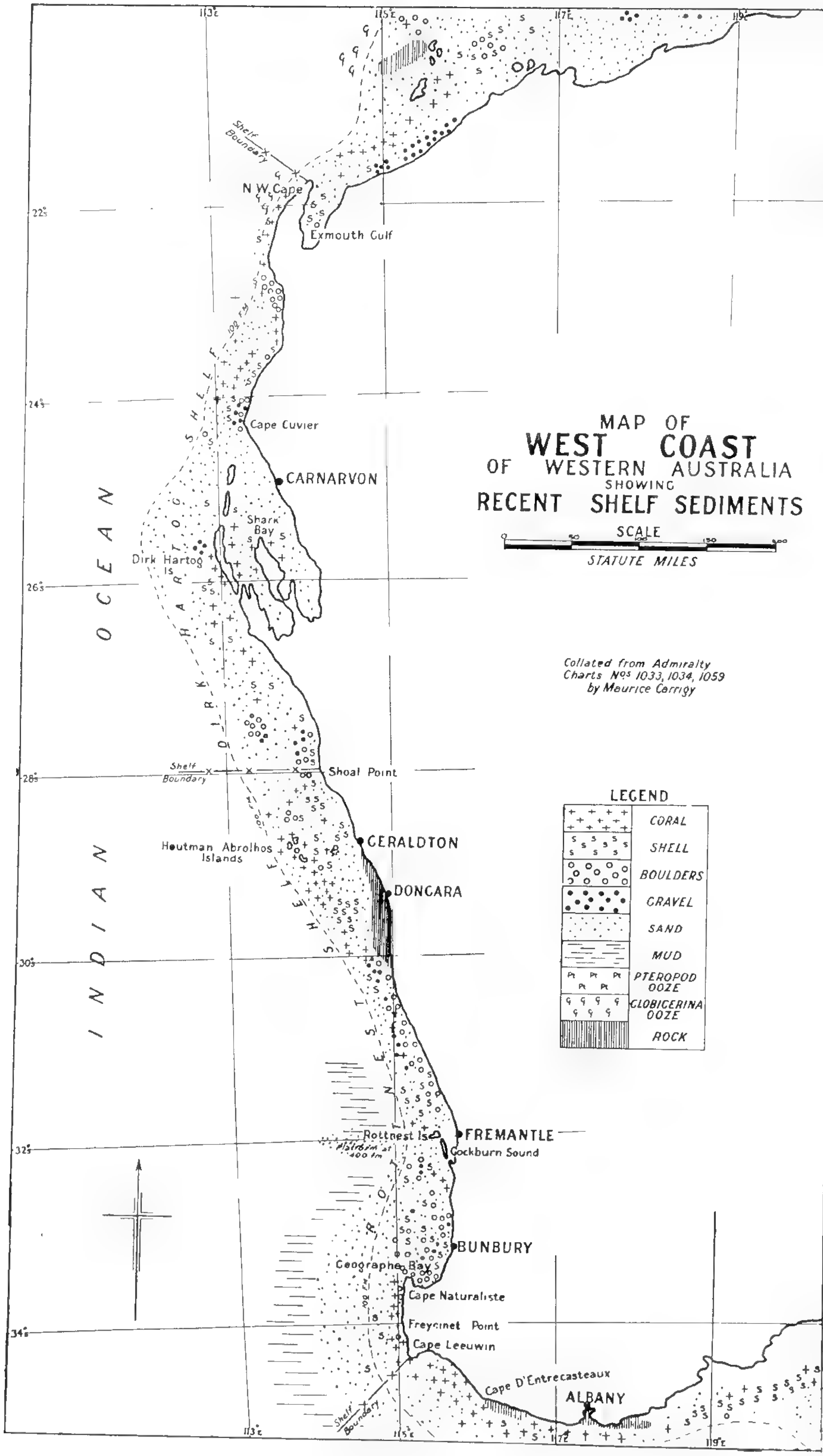
(*c*) areas of no active terrigenous sedimentation.

These divisions may be correlated directly with the physiography of the hinterland. On all the shelves, organogenic sedimentation is very general, but slow. Only locally, such as around coral reefs is it rapid.

(a) Areas of Moderate Terrigenous Sedimentation

From a study of the rather arid physiography of Western Australia, one would not expect the areas of moderate terrigenous sedimentation to be very numerous. They are confined to inner parts of the Sahul Shelf opposite the well-drained Kimberley block. Here, during the wet season there is considerable precipitation over a short period (25 to 30 inches from November to April). The rivers flood and for a short time carry down to the sea large quantities of debris, which is picked up by the strong tidal streams of 5 to 10 knots in the estuaries and carried offshore. It is further spread by the variable sets of the ocean currents. Thus, on this broad shallow shelf, fine and coarse sediments are mixed and spread very thinly and uniformly over the surface. The large expanses of rock bottom inshore can be explained by the scouring action of the strong tidal currents which carry away the fine sediments. In sheltered estuaries and bays, e.g. King Sound, there are extensive mud flats, partly covered by mangrove.

Towards the margin of the inner shelf in 30-60 fathoms (especially from 14°S. 123°E., 16°S. 121°E.; see text-fig. 6) and also on the outer shelf near the Sahul Banks, there are bands of sand and gravel such as are found near the edge of many other continental shelves. Even at points on the shelf edge well removed from contemporary coral reefs there are still coral sands and debris, which suggests reef erosion and littoral sedimentation during a low Pleistocene sea level, followed by a period of non-deposition until today. The composition of these coarse coral sediments near the shelf edge is almost 99 per cent. $CaCO_3$ (Kuenen and Neeb, 1943). However, away from coral reefs, over broad stretches in the intermediate depths of the shelf, scattered reports indicate that shell and foraminiferal debris amounts to


MAP OF
WEST COAST
OF WESTERN AUSTRALIA
SHOWING
RECENT SHELF SEDIMENTS
SCALE
STATUTE MILES
Collated from Admiralty Charts Nos 1033, 1034, 1059 by Maurice Carrigy
LEGEND
CORAL
SHELL
BOULDERS
GRAVEL
SAND
MUD
PTEROPOD OOZE
GLOBIGERINA OOZE
ROCK
INDIAN OCEAN
DIRK HARTOG SHELF
ROTTNEST SHELF
Shelf Boundary
N.W. Cape
Exmouth Gulf
Cape Cuvier
CARNARVON
Shark Bay
Dirk Hartog Is.
Shoal Point
Houtman Abrolhos Islands
GERALDTON
DONGARA
Rottnest Is.
FREMANTLE
Cockburn Sound
BUNBURY
Geographe Bay
Cape Naturaliste
Freycinet Point
Cape Leeuwin
Cape D'Entrecasteaux
ALBANY

Text fig. 7.

only 25-50 per cent. $CaCO_3$ while the balance consists of fine terrigenous material, with the important alteration product glauconite; the shelf sediments here may be best described as glauconite muds and sands (Fairbridge, 1953). The mineral glauconite is indicative of slow or even interrupted sedimentation, so it is apparent that the relatively large seasonal supply of sediment from the land is insufficient to cover such a very broad shelf. In any case, during the long dry season, there is practically no supply of terrigenous material, except for a small amount of fine air-borne red dust brought in by the off-shore trade wind.

Kuenen (1939, 1950b) suggests that at the edge of the shelf the water is agitated and deposition of fine sediment is prevented. The situation here is not favourable to the slumping hypothesis of Fairbridge (1947). In the deep ocean off the shelf there are fine terrigenous sediments again, which appear to have been carried over the edge of the shelf by currents. Apparently, turbulence develops near the edge of any notable break in slope, and is of sufficient velocity to remove the fine particles, leaving the coarse behind. Such breaks in slope are provided at the edge of every shelf and intermediate terrace.

The sediments on the other shelves show an essentially "normal distribution" with the coarsest material on the inner shelf and the finest at the shelf edge and in the ocean basins. In these cases the shelves are relatively narrow, there are few coral reefs, and both currents and the tidal range (and thus turbulence) are more restricted.

(b) Areas of little active terrigenous sedimentation

The shelves from North-West Cape to Cape Leeuwin (i.e. Dirk Hartog and Rottnest Shelves) fall into this category. The rivers flowing into the ocean here carry little sediment except in occasional floods when large quantities of debris may be transported for very short periods (see Finucane and Forman, 1929; Carroll and Clarke, 1940). Samples in this sector show very little trace of recent terrigenous material, the composition being almost entirely restricted to organogenic clastics and reworked quartz sands together with certain resistant heavy minerals.

The reason for this almost complete lack of recent terrigenous additions may be found in the physiography of this 1000-mile sector. Over the 500-mile length of Dirk Hartog Shelf the hinterland is extremely arid and there are only two rivers entering the sea, these generally flowing for only a few weeks of the year. As to the 500-mile Rottnest Shelf, although the hinterland locally receives 20-40 inches of rain, there are less than one dozen rivers or streams, all of which are intermittent, and have broad drowned estuaries that act as sediment traps; most of them have barred mouths unless artificially kept open. The coast line

itself is either sandy or consists of low cliffs mostly of a Pleistocene aeolianite which itself is composed of residual quartz sands and clastic organogenic material, hardly distinguishable from the contemporary littoral sediments. Coastal erosion, however, tends to be slight owing to protective sandstone (and locally coral) reefs. There is, on the other hand, a certain amount of wind-borne terrigenous sediment in the northern and more arid sectors.

Accordingly the characteristic contemporary sediments on these shelves are calcareous and organogenic (foraminifera, broken shells, algal debris, etc.) with a small proportion of hard insoluble residual minerals. A typical example from the Rottnest Shelf in 10 fathoms is composed of 40 per cent. shell fragments, 4 per cent. rounded quartz grains, 2 per cent. bryozoa, less than 1 per cent. foraminifera, the remaining 53 per cent. of the sample consisting of unidentifiable fragments. On the continental slope of the Rottnest Shelf in 400 fathoms the sediment consists of a spicular ooze made up of 50 per cent. shell fragments, 28 per cent. sponge spicules, 8 per cent. foraminifera, and the remaining 14 per cent. small fragments of gastropods, faecal pellets, but mostly unidentifiable calcareous material. A sample from the Eucla Shelf in 25 fathoms is composed of 26 per cent. shell fragments, 3 per cent. foraminifera, 2 per cent. bryozoa, 5 per cent. rounded quartz grains; the remaining 64 per cent. consists of unidentifiable calcareous fragments.

(c) Areas of no active terrigenous sedimentation

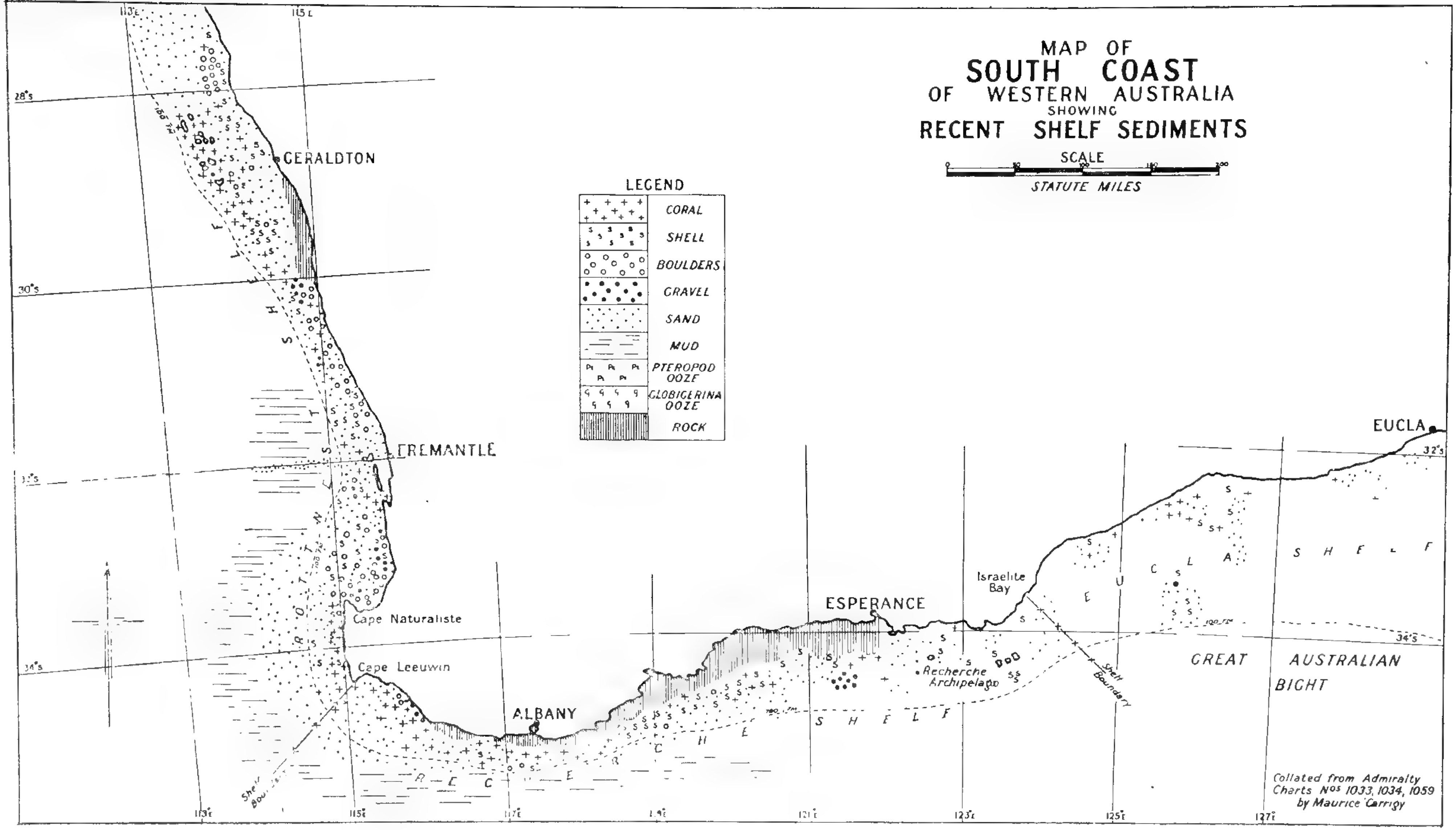
Strictly speaking there is no area completely without terrigenous sedimentation, but on some of the West Australian shelves this condition must be closely approximated.

On the arid side of a mature continent in sectors where the rainfall is less than 5 to 10 inches per annum, the shelves would never receive large quantities of sediment. There are, in fact, two areas off Western Australia where there is no external drainage from the mainland whatever:—

(i) That part of the Rowley Shelf opposite the 80-mile Beach.

(ii) The Eucla Shelf, almost along its entire length. In both of these areas the supply of terrigenous sediment is restricted to that supplied by offshore winds, wave erosion or small amounts brought in by longshore currents.

In a different category is the Recherche Shelf. In this case the lack of terrigenous sediment is not due to climatic conditions (being for the most part in the 25-inch rainbelt), but because the shelf is narrow and constantly scoured by storms;


MAP OF
SOUTH COAST
OF WESTERN AUSTRALIA
SHOWING
RECENT SHELF SEDIMENTS
SCALE
STATUTE MILES
LEGEND
CORAL
SHELL
BOULDERS
GRAVEL
SAND
MUD
PTEROPOD OOZE
GLOBIGERINA OOZE
ROCK
GERALDTON
FREMANTLE
Cape Naturaliste
Cape Leeuwin
ALBANY
ESPERANCE
Israelite Bay
Recherche Archipelago
EUCLA
Shelf Boundary
GREAT AUSTRALIAN BIGHT
Collated from Admiralty Charts Nos 1033, 1034, 1059 by Maurice Carrigy

Text fig. 8.

also the rivers mostly debouch into barred estuaries which act as sediment traps; finally the mainland behind is of hard Pre-Cambrian rocks and thus is not subject to rapid erosion.

3.—Coral Reefs on the Shelves

Contrary to general belief there are numerous coral reefs bordering the western coast of Australia. These have been treated in various papers by Fairbridge and Teichert (see review and bibliography: Fairbridge, 1950b). There are many atolls and coral islets on the Sahul and Rowley shelves, important examples being Adele, Browse, Cartier, Seringapatam, and Scott Reefs on the Sahul Shelf, and Mermaid, Clerke, and Imperieuse Reefs, known collectively as the Rowley Shoals, on the Rowley Shelf.

These coral shoals at the edge of the shelf rise almost vertically from 300 fathoms. They clearly indicate recent subsidence of the shelf edge (Teichert and Fairbridge, 1948). Reef corals are associated with the continental islands nearer the coast, in the Buccaneer Archipelago and in the Dampier Archipelago (as fringing reefs) and with the "standstone reefs" (i.e. Coastal Limestone) extending from North-West Cape to south of Rottnest Island (Fairbridge, 1950a; Teichert, 1950). The most southerly true coral islands in the Indian Ocean are the Houtman's Abrolhos Islands (lat. $28\frac{1}{2}°$ S).

In the vicinity of all these reefs there are the usual coral sediments, corals in position of growth being surrounded by extensive areas of coarse and fine coraligenous clastics. In the lagoons there are frequently the white calcareous muds that are believed to be precipitated under favourable physico-chemical conditions (Fairbridge, 1948).

4.—The Nature of the Sediment on the Shelves

From these preliminary studies it is apparent that the principal sediments on our continental shelves are clastic calcareous materials of organogenic nature such as algal remains, shell fragments and foraminifera. To a lesser extent they are the products of aeolian and marine erosion reworking older sedimentary formations, especially the Pleistocene aeolianite or "Coastal Limestone." Only minor quantities of calcareous material are due to chemical precipitation and then just in restricted localities. Primary terrigenous sediment is largely confined to those sectors where there is a high rainfall and strong tidal flow. The geological significance of these conclusions will be discussed in section IX.

The continental shelves of Western Australia are thus the sites of accumulation for large quantities of calcium carbonate-rich sediments of organogenic origin. They are not by any means restricted to the tropics but extend as far south as lat. 35°S. (where there is a mean winter surface water temperature of 13°C. and a summer surface water temperature of 19°C.), and

in south-eastern Australia as far south as lat. 40°S. A sediment of this sort would correspond in the geological column to a widespread pure organogenic limestone with few macro-fossils. Although macro-organisms are abundant on the shelf the slow rate of deposition and constant re-working prevents their preservation. The theoretical aspects of this type of deposition have already been discussed by Twenhofel (1942).

V.—BATHYMETRY OF THE ADJACENT OCEAN

That part of the Indian Ocean adjacent to the coast of Western Australia is not well known. The latest general chart appears to be the "Carte Générale Bathymétrique des Océans" sheet No. AIII (1942) but slight modifications have been added by Vening Meinesz (1948). Morphologically the sea floor here may be divided into various troughs, basins, deeps, swells, ridges, rises and sills (as indicated on text-fig. 1), and although these charts show only the major features, they are enough to indicate that a fundamental relationship exists between the floor of the ocean and the tectonic pattern of the West Australian continental mass.

The main element of the north-eastern Indian Ocean is the *India-Australian Basin* (of Schott, 1935) a very broad area of about 3,000 fathoms depth which includes the Wharton Deep. In the light of more recent soundings it seems desirable to distinguish a *North Australian Basin* which is almost separated from the former by the 2,000-fathom line, marking a low interrupted sill which extends along the meridian 112-113°E. in the direction of East Java. The latter broadens off the north-western end of the Rowley Shelf as a broad dome, all under 2,000 fathoms which we have termed the *Exmouth Rise,* after Exmouth Gulf. Another small basin, also almost cut off from the India-Australian Basin by a lobe of the Exmouth Rise, lies to the south, and we have called this the *Cuvier Basin,* after Cape Cuvier on the adjacent coastline; it is almost 3,000 fathoms deep. This in turn is bounded on the south by the *West Australian Ridge* (of Vening Meinesz, 1948) which forms a remarkable spur extending nearly 800 miles into the Indian Ocean in a north-westerly direction from the middle of the west coast (Abrolhos Rise). To the west lies the broad *West Australian Basin* (of Vening Meinesz, 1948) which is mostly over 3,000 fathoms deep. This feature is limited on the south by the *South-West Australian Ridge* (of Vening Meinesz, 1948), which appears to be arcuate and parallel to the south-west coastline; it is marked by several sections of under 1,000 fathoms depth. This ridge is connected to the south coast by an ill-defined sill of 2,000 fathoms which we have called the *Leeuwin Sill* since it extends due south from Cape Leeuwin. It separates the West Australian Basin from the *South Australian Basin* (Schott, 1935), which contains the Jeffreys Deep.

VI.—TECTONICS IN RELATION TO SHELVES AND ADJACENT OCEAN

1.—The Pre-Cambrian Trends

The Pre-Cambrian Shield or "craton" of Western Australia may be divided into areas that over considerable periods have been dominantly positive or else dominantly negative in respect of movements. These have occurred again and again since the Pre-Cambrian but the elevations and depressions seem to have maintained their relative positions. The amplitude of this warping is found to increase towards the margins of the "craton."

(a) Positive areas, generally known as swells, platforms, blocks, domes and rises; they may or may not have a thin veneer of sediments.

(b) Negative areas, usually called basins, and most of the West Australian examples are classified by Umbgrove (1947) as his "discordant basins (type IV)," although their margins are in part parallelled by the later trends, being superimposed on the orogenic trends of the Pre-Cambrian basement.

The tectonic patterns of the Pre-Cambrian in Australia are arcuate and closely follow the continental outline. (See text-fig. 1; in part, as shown by Hills, 1946, 1947). Three main nuclei are recognised in Western Australia, corresponding to the positive Yilgarn, Pilbara and Kimberley Blocks. The Nullagine Platform is an intermediate feature which has remained relatively undisturbed since Proterozoic times. The West Coast marginal belt is also Proterozoic, but may have been geosynclinal in character (Hills, 1946). Recently a further important feature has been recognised in the "South Coast Province" by Prider (1952), where the trends again closely follow the continental outline, cutting off at right-angles the submeridional lineaments of the central or Yilgarn Block.

The younger sedimentary basins have been described by Teichert (1947), who noted that in the major basins the sediments increase in thickness toward the continental margin. Gibb Maitland (1919) in his artesian water studies named these basins "Desert," "North-West," etc. Clarke (1926a) in his "Natural Regions" preferred geographical names. It would seem good practice to apply the geographical names to the basins and to drop the vague description terms of Maitland (see geomorphological map: Gentilli and Fairbridge, 1951).

In the "Desert" or Canning Basin near Broome, Teichert (1947) estimates 14,000 feet of Upper Palaeozoic and Mesozoic sediments. In the "North-West" or Carnarvon Basin (of Clarke, 1926a) the sediments range in age from Devonian to Tertiary. The Swan Coastal Basin probably has its maximum thickness of sediments in the vicinity of Perth. Teichert conservatively estimates 6,000 to

7,000 feet of Permian to Recent sediments in this area. Some 3,000 feet of unmetamorphosed Proterozoic Sediments also outcrop here (Fairbridge, 1950d), but recent gravimetric work suggests that a total of 20,000 to 40,000 feet of post-crystalline sediments may be found here (Thyer, 1951a). The Eucla Basin sediments are thickest at the coast and Teichert (1947) gives 2,000 feet of Cretaceous to Tertiary.

As a general rule it can be stated that the positive areas of the West Australian shield are bounded seawards by convex coastlines and the negative areas are bounded by concave coastlines.

2.—The Tectonic Boundaries of the Shelves

The structural boundaries of the Sahul Shelf have been fully described by Fairbridge (1953). The Rowley Shelf is bounded in the south-west by a very narrow shelf at North-West Cape, which would appear to be fault controlled (Fairbridge, 1950c). The south-west boundary of the Dirk Hartog Shelf may be related to a series of N.N.W.-S.S.E. trending wedge-shaped blocks which Fairbridge (1950c; also in Clarke *et al.* 1951) attributes to faulting (the Hill River Fault, Geraldton or Moonyoonooka Fault, see text-fig. 1). The Abrolhos Rise forming the southern boundary of this shelf (at 28°S.) corresponds closely to where one would expect the marginal culmination of one of these blocks. Separating the Carnarvon and Swan Sedimentary Basins is the Northampton-Greenough Block, the largest occurrence of the Pre-Cambrian basement granites and gneisses west of the Darling Fault at about $28\frac{1}{2}$°S. lat. Projecting far into the Indian Ocean, the West Australian Ridge may represent the prolongation of these ancient structures.

The Rottnest Shelf is bounded in the south by the N.-S. Leeuwin-Naturaliste Ridge or "Horst" (Woodward, 1916) where the coastline changes its trend from N.-S. to E.-W. The general E.-W. trend of the Recherche Shelf parallels exactly the South Coast Pre-Cambrian trends. The eastern boundary of this shelf is situated at Israelite Bay, where the shelf character suddenly changes from a Pre-Cambrian to a Tertiary basement in the Eucla sedimentary Basin. The very steep continental slope of the Eucla Shelf is suggestive of faulting as are the high cliffs on the coast (Jutson, 1934), which merely represent the extension of the Hampton Fault farther west.

VII.—GEOPHYSICAL OBSERVATIONS

1.—Gravimetric

The West Australian shelves have been traversed several times by the gravity expeditions of Vening Meinesz. His results show that the greater part of the ocean floor adjacent to Western Australia is in isostatic equilbrium, but interesting deficiencies of gravity have been shown to occur under the Rottnest Shelf in the

vicinity of Fremantle. Here an anomaly of - 140 milligals occurs under the continental shelf and the Swan Coastal Plain but equilibrium is again restored after the Darling Fault is crossed. A very steep isostatic gradient over this fault suggested a throw of 20,000-40,000 feet (Thyer, 1951a). The Carnarvon (or "North-West") Basin shows a complex pattern of positive and negative anomalies which appear to correlate with a faulted basement (Thyer, 1951b) the pattern closely resembling that to the south. Another deficiency of gravity was found by Vening Meinesz over the Exmouth Rise where an anomaly of - 150 milligals exists. This large figure, when considered in conjunction with the earthquake of 1906 which occurred in the area, suggests that the Exmouth Rise may be a foundered continental block of comparative youth. Several smaller undulations to the north on the sill of the North Australian Basin show smaller negative isostatic anomalies.

Profiles onto the Sahul Shelf show that it is in a state of isostatic equilibrium (Vening Meinesz *et al.*, 1934), but an intense belt of negative anomalies parallels the Timor Trough, which may explain recent subsidence of coral reefs near the shelf margin (Fairbridge, 1950b).

2.—Seismic

The few earthquake shocks that have occurred on the western side of Australia have been collated by Gutenberg and Richter (1949, figure 30). The large shock of November 19th 1906, plotted at 22°S 109°E. coincides with the margin of the Exmouth Rise and the Cuvier Basin; it was a shallow class *a* shock. Another shallow shock, class *d*, occurred off the north-west coast (16½°S 121°E.) on August 16th, 1929, on the edge of the Rowley Shelf, not far from the Leveque Rise. A third shock of class *d* occurred on July 12th, 1934, on the rise separating the India-Australian Basin from the North Australian Basin (15°S 112½°E.). A fourth shock occurred on April 26th, 1941, class *c*, shallow shock at about 26½°S 117°E., on the upper Murchison, probably a movement along a fracture near the margin of the Pre-Cambrian shield. A fifth, on February 8th, 1920, is plotted as a shallow shock, class *d*, at 35°S 111°E., coinciding with the South-West Australian Ridge. There is no doubt that seismicity is rare along this coast, but the paucity of records may be partly due to the limited number of observation stations—the nearest being in Perth, Sydney and Java.

VIII.—ORIGINS OF THE WESTERN AUSTRALIAN SHELVES

From the geotectonic point of view Western Australia is best described as a "craton" (i.e. a semi-rigid shield area with less rigid intermediate shelf and intra-cratonic basin areas), and consequently has been regarded as the most stable part of the continent. The gravity surveys of Vening Meinesz nevertheless show a large negative isostatic anomaly over the Rottnest Shelf. If it were assumed that the shelves have remained relatively

stable for long periods it might also be concluded that they would represent a profile of equilibrium due to marine erosion in conjunction with uniform eustatic oscillations, but it is found that the break of slope varies in depth from 70 fathoms on the Eucla Shelf and 100 to 150 fathoms at North-West Cape to 300 fathoms on the Rowley and Sahul Shelves, and that the width of the shelf varies from about 24 miles to 250 miles. It is very difficult to attribute these irregularities to differential erosion when the narrowest shelf at North-West Cape is cut in soft Tertiary rocks, while the broad Sahul Shelf off the Kimberley is carved mainly into the hard Pre-Cambrian basement. One must conclude, that long-continued stability is not a feature of all these shelves.

Even a preliminary consideration shows clearly that there is no one causal phenomenon that accounts for all sectors of these continental shelves. Accordingly the origin of each of the Western Australian shelves will be analysed and finally the principles of shelf formation will be briefly discussed.

1.—The Sahul Shelf

Here the topography suggests a former subaerial exposure, shown by submerged land forms of arid type with clear terraces, shallow canyons and traces of older rock structures (Fairbridge, 1953). It was also a Pleistocene migration route. These facts suggest eustatic emergence. However, in places the shelf edge is marked by coral atolls and banks rising for 300 fathoms or so which suggests tectonic marginal subsidence (Teichert and Fairbridge, 1948). It is possible to assume downwarping of the continental margin induced by the mobile arcs of the East Indies; this is supported by the apparently faulted edges of the Timor Trough (Molengraaff, 1914), and the band of negative gravity anomalies paralleling the outer Banda Arc (Vening Meinesz *et al.*, 1934). This subsidence is contrasted by the updoming in the Kimberley Block.

The rock structures and continental islands on the shelf opposite the north-west Kimberley indicate an eroded platform, but opposite the Bonaparte Basin (in Cambridge Gulf; see Shepard 1948, fig 53; Fairbridge, 1953) there is evidence of heavy sedimentation into a closed depression on the Sahul Shelf.

Here thus we have an excellent example of a composite shelf, features of which require variously: eustasy, tectonics, erosion and sedimentation for their explanation.

2.—The Rowley Shelf

This is another composite shelf. There is evidence that suggests that it is being actively downwarped in the area opposite the Canning Basin:—

(*a*) the break in slope is normal (100 fathoms) at North-West Cape and at 300 fathoms opposite Eighty-Mile Beach;

(*b*) the atolls of the Rowley Shoals rise sheer from the edge of the shelf at 300 fathoms (see text-fig. 2, see also Teichert and Fairbridge, 1948);

(*c*) the concave outlines of the coastline and shelf edge;

(*d*) the increasing width of the inner and outer shelves from North-West Cape to a mid-point opposite Eighty-Mile Beach.

The central part of this shelf is probably an accumulation of sediments and the geological evidence (Teichert, 1947) indicates that it has been a negative area since early Palaeozoic times. It probably represents an accumulation of sediments by trangressive overlaps and regressive offlaps forming a great wedge of sediments such as occurs off the east coast of North America (see Ewing *et al.*, 1950), or around the Gulf of Mexico, and may perhaps contain potential oil traps.

The contemporary subsidence on the Rowley Shelf is particularly clear because there is at present no active sedimentation in this area. Had the shelf been off a coast of some sedimentation its origin might have been much less obvious.

The centre of this regional subsidence may be in the North Australian deep sea basin, and its inner limits are probably represented by the Pre-Cambrian borders of the Canning Basin, the total area involved being some 400,000 square miles.

3.—The Dirk Hartog Shelf

This shelf is the most complex and also the least known, bathymetrically, of the shelves. That marine erosion is not very active is shown by the occurrence of large islands of late Pleistocene rocks enclosing the bay, e.g. Dirk Hartog, Bernier, Dorre Islands and also Peron Peninsula.

This shelf must be influenced tectonically on the one side by the Dampier Rise, West Australian Ridge and Cuvier Basin, and on the other by several units on the continent. The Carnarvon Basin on the mainland appears to be broadly continuous with the Cuvier Basin offshore, and has a faulted contact at its inner margin against the Pilbara Block (Teichert, 1947). Artesian borings indicate that the sediments are thickest in the vicinity of Exmouth Gulf where the shelf is narrowest. Fairbridge (1950c) believes faulting may account for the narrow shelf. Teichert (1947) mentions a Pliocene or even younger age for the latest movements. The final elucidation of this area will not be forthcoming until further fieldwork has been completed.

4.—The Rottnest Shelf

This is one of the narrow shelves; it appears to be a sedimentary feature, moulded by downwarping and faulting (Jutson, 1934) and modified by eustatic changes of sea level which have drowned Pleistocene erosion features, e.g. Swan River estuary.

The most important factors in its formation have been:—

(i) progressive downwarping, passing into faults at the inner margin and outer margin, accompanied by sedimentation;

(ii) the topographic sculpturing during eustatic lowering of sea level in the Pleistocene;

(iii) the superficial deposition of aeolianites along Pleistocene shore-lines.

Sedimentation appears to have been able to keep pace with the downwarping, an hypothesis which is favoured, apart from purely geological data, by the negative isostatic anomalies.

Apart from its narrowness and more faulted nature, its history is roughly comparable to that of the Rowley Shelf.

5.—The Recherche Shelf

This lies on the southern borders of a positive belt of Pre-Cambrian age and moderate elevation, the southern margins of which have been rather deeply dissected in the past. Sedimentation during the Tertiary has partly filled in this old topography, so that the present shelf is cut in soft sediments (forming smooth and flat platforms) punctuated by abrupt ridges and islands, which are the old hilltops of the resistant Pre-Cambrian rocks belonging to the pre-Tertiary subsided and drowned landscape. It is relatively narrow and shallow, and suggests an imperfect platform of marine erosion of some antiquity possibly modified by Pleistocene eustatic changes of sea level, which are responsible for a series of terraces. The continental slope is very steep (1 in 10) which is strongly suggestive of a faulted margin.

6.—The Eucla Shelf

This appears to be an essentially organogenic sedimentary feature of Tertiary age, slightly modified by late Tertiary erosion and by Pleistocene eustatic terracing, as shown by:—

(i) smooth floor with subdued terracing;

(ii) its juxtaposition to the Eucla Basin, with its lens of Cretaceous-Tertiary sediments resting on a downwarped Pre-Cambrian floor. Its margins appear to be faulted, both at the coast (Jutson, 1934) and at the shelf edge (Serventy, 1937) but more soundings are needed.

IX.—DISCUSSION AND CONCLUSIONS

The broad features of the sediments and morphology of the continental margin of Western Australia and the adjacent ocean floor have been analysed and named, and their possible origins have been discussed in the light of the physiography, tectonics and geological history. The suggestions advanced may help to explain some complexities of shelf formation in general, and may indicate areas of possible economic importance in the search for oil. It has been shown that although continental shelves are always present, their origins are not always the same. In every case in Western Australia we have found a genetic relationship between shelf and hinterland; in each case they are structually a single or related unit. Oceanwards the same structural tendencies seem to persist.

The factors involved in the formation of West Australian shelves are as follows:—

(a) Tectonic deformation in varying degrees, on all shelves. Most have been downwarped or sagged between positive upwarps.

(b) Sedimentation, variable, but maximum in shelves opposite sedimentary basins, the Rowley, Dirk Hartog, Rottnest and Eucla Shelves.

(c) Marine erosion, variable susceptibility according to local rock types, e.g. the Recherche Shelf.

(d) Eustatic changes of sea level, on all the shelves, but partly dependent on *(c)*.

In the sense that every shelf is the result of these and other factors, all shelves are complex and of compound origin. It appears from the palaeogeographic reconstructions by Teichert (in Clarke *et al.*, 1944), that the continental outline of Western Australia has not changed fundamently since Nullagine (late Pre-Cambrian) times, when the northern part of the shield was covered by a shallow sea. The Canning, Carnarvon, Swan and Eucla sedimentary Basins appear to be sediment-filled transitional depressions on the landward side of the North Australian, Cuvier, West Australian and South Australian deep sea basins respectively. Considerable geophysical inequalities are suggested by the large negative gravity anomalies off the corresponding shelves. From the limited seismicity it would seem that present mobility was low. Evidence from atolls and reefs on the edges of the Rowley and Sahul Shelves indicate that some downwarp is still in progress, although on the Rowley Shelf sedimentation has practically ceased; thus the sedimentation must be entirely secondary to the subsidence of the major basin.

The accumulation of large quantities of sediment near the inner margins of deep sea basins in former times does not lend support to the hypothesis of continental drift—at any rate as

regards the younger geological periods; indeed it suggests that the difference between the surface crust of the continents and ocean floor here is one of degree rather than of kind.

At the conclusion of a study of contemporary sedimentation and its environments, it is natural for geologists to consider how these recent facies would appear in the stratigraphic column. The Western Australian continental shelf environments extend over a linear distance of 4,000 miles and range from 24 to 250 miles in width, and up to 500 miles or more if we include the coastal basins. Over this enormous area there is only a single mega-facies having the following characteristics:—

1. Slow accumulation and uniform mineralogy:

(a) Organogenic calcareous sands of shell or coral fragments, with local concentrations of bryozoa, foraminifera, algal fragments. On the outer Rottnest and Eucla shelves there are very well-rounded and sorted calcareous sands.

(b) Reworked sands, i.e., well-rounded quartz sands, with minor resistant heavy minerals.

(c) Glauconites.

2. General scarcity of macro-fossils, except in beach rock and in protected lagoons, bays and estuaries, e.g., Warnbro' Sound, Cockburn Sound and associated with reefs ("sandstone" and coral). This scarcity is attributed partly to the destruction of shells by scavenging and boring animals and plants.

3. Uniformity of fauna along thousands of miles of coastline, though an almost imperceptible change in fauna occurs north of the Abrolhos Islands where there is a gradual transition from temperate to subtropical faunas.

4. Bioherms and biostromes very widespread:

(a) Bioherms are of coral and confined to the tropical and subtropical areas.

(b) Biostromes—bryozoan patches cover many square miles in all latitudes; similarly vast beds of pearl oysters are common in the warmer regions.

5. Landwards the shelf deposits interfinger (due to eustatic oscillations) with calcified beach rock and beach conglomerates, narrow belts of aeolianites (100-500 feet thick) with fossil soils, leached coastal plain residuals of pure quartz sand, local estuarine silts, clays and grits.

6. Oceanwards the shelf deposits grade progressively (beginning at depths of 100-400 fathoms) into:—

(*a*) spicular ooze;

(*b*) *Globigerina* ooze;

(*c*) Pteropod ooze;

(*d*) abyssal red clay.

The above outlined mega-facies was clearly produced by slow, uniform, neritic sedimentation associated with an arid, ancient landmass of low relief. Destruction of marine shells in such sediments dominated by sands is widespread, either contemporaneously by abrasion (mega-fossils) and biologically by scavengers and borers, or subsequently by leaching (micro-fossils). Owing to eustatic oscillations, sediments forming on a shallow, stable shelf may be reasonably expected to be exposed periodically to subaerial erosion and in the case of calcareous sediments the resultant leaching may seriously alter the original appearance of the rocks. In extreme cases, the calcium carbonate will be largely removed and the remaining rather characterless sediments may be difficult to distinguish from leached continental beds in the adjacent coastal plain, since both will be essentially residual and non-fossiliferous and the grains may be angular, or well-rounded, wind blasted, coarse and fine with limited lenticular clayey materials; only in particular belts (e.g. aeolian ridges) and in restricted local basins will there be appreciable limestones. In the latter one may seek pockets of macro-fossils. Pockets of highly fossiliferous beach-rock, rapidly consolidated (and thus preserved from normal leaching), may disclose an original strandline. Similar pockets of fossils in littoral and shallow facies will mark former reefs, bays and estuaries. The relative improbability of striking such local indications in the limited exposures of a paralic basin sequence will inevitably render the latter difficult to map and correlate.

Nevertheless such eustatic (and tectonic) oscillations as occurred during the Pleistocene may not have been constantly in progress throughout all geological periods, so that at least in the outer parts of the shelf one may expect perhaps to find broad belts of organogenic lime sands developing, and with the assistance of marginal subsidence, reaching moderate thickness. One may expect the incidence of micro-fossils preserved to rise here.

When considering how this giant mega-facies would appear in the stratigraphic column, it would be wrong to imagine that it would be of equal thickness along the 4,000 miles studied. Conclusions regarding the structure of each of the six shelves described indicate there is a succession of positive and negative sectors; so that, in fact, the positive areas will be scenes of repeated erosion or at least, non-deposition or non-accumulation. Probably only at times of eustatic submergence will this process

be periodically reversed. The more or less continued accumulation of this paralic facies will only take place in the tectonically negative areas and these will be found only in well-separated lenticular deposits when viewed along the "strike" of the original shelf.

Still considered as a stratigraphic problem, it might be expected that each of these lenticles, or marginal basins, would be distinctive, having derived its sediments from a separate section of the hinterland, and being separated from the lenticle next to it. To some extent this is true, but to a far greater extent one may expect lithological uniformity from basin to basin within any one geological stage, because there was an oceanographic continuity over the sectors of non-deposition, permitting free migration of faunas, uninterrupted movement of sediment, and a uniform physical condition to be maintained. Further similarity in the sediments will be imposed by the climatological and geological uniformity of the hinterland, which may not change greatly from basin to basin.

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